



两大领域前沿成果展示
国内与国外专家汇集
学术研究与技术应用兼备
来自 28 个国家和地区

国内外最新 继电保护及控制技术研究 (下册)

中国电机工程学会继电保护专业委员会 编



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内 容 提 要

本书是第六届现代电力系统自动化和保护国际学术研讨会（APAP2015）论文集，收录了来自 20 个国家和地区的 174 篇论文。这些论文反映了国内外电力系统继电保护和自动化业界共同关注的问题及最新研究成果，内容涉及继电保护、变电站自动化、电网安全稳定控制、电网运行及分析、高压直流输电及电力电子设备控制保护、分布式发电、配电网保护和控制等。论文集内容丰富，实用性强，对电力系统保护和控制技术研究有较高参考价值和借鉴意义，可供相关学者、专家以及工程技术人员参考。

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前 言

中国电网是世界上发展最快的电网。大容量远距离、交直流混联电能输送，大规模可再生能源接入，以及新一代电力电子设备的应用，满足了中国经济发展在电能生产与输送方面的需求，也给继电保护、自动化和控制系统带来了许多新的问题和挑战。

现代电力系统自动化和保护国际学术研讨会（APAP）于 2004 年由韩国明知大学 Lee Seung-jae 教授发起，其目标是为电力系统继电保护和自动化领域的专家、学者搭建一个国际性的学术交流平台。同年 10 月，在韩国济州岛召开第一次会议。2007 年、2009 年在韩国济州岛召开了第二次、第三次会议。2011 年在中国北京召开了第四次会议。2013 年 10 月在韩国济州岛召开了第五次会议。

南京素有“江南佳丽地，金陵帝王州”之美称，也是中国科技最为发达的城市之一。在这座古老而又现代的城市里，聚集着大批电力自动化企业，已成为中国该领域最重要的研发和产业化基地。他山之石，可以攻玉。为借鉴国际同行的研究成果和运行经验，应对面临的问题和挑战，中国电机工程学会继电保护专业委员会决定在南京承办第六届现代电力系统自动化和保护国际学术研讨会（APAP2015），并将会议主题确定为“当前和未来电力系统中保护、自动化和控制系统面临的机遇与挑战”。相信广大与会代表能在这个平台上结识同行，分享新思想、新技术、新经验，共同推进本行业技术进步。

研讨会的征文和筹备，得到了相关各方大力支持和协助。研讨会共收到来自 22 个国家和地区的论文摘要共 268 篇。经评审，最终录用 174 篇，汇编成集。值此论文集出版之际，我们衷心感谢所有关注、支持和帮助本次研讨会的单位和个人。

中国电机工程学会继电保护专业委员会

2015 年 9 月

Foreword

Electric power system in China experienced the fastest development around the world in the past decades. Application of bulk long-distance power transmission on hybrid AC / DC transmission lines, adoption of large-scale renewable energy generation, installation of new generation power electronic equipments, meet the needs of China's economy development on electric energy generation and transmission, but also bring about many new problems and challenges to protection, automation and control system.

APAP was initiated in the year of 2004 by Professor Lee Seung-Jae from Myongji University in Korea. The goal of APAP is to build an international platform for experts, scholars and engineers to carry out academic exchanges in the field of electric power system protection, automation and control. The 1st APAP was held in October of the same year, followed by the 2nd one in 2007, and the 3rd one in 2009 in Jeju Island, Korea. The 4th one moved to Beijing, China in 2011, and the 5th one returned to Jeju Island in October 2013.

Nanjing is known as the "Beautiful place in the south of the Yangtze River and imperial state at Jinling" in the history. Now she is one of the most developed cities in high technology. With a large number of electric power automation enterprises, this ancient and modern city has become the most important research and manufacture base in this field. Wise men learn by other's mistakes. In order to learn from research results and operation experience around the world, to deal with the problems and challenges facing today, Relaying Protection Study Committee of CSEE (Chinese Society for Electrical Engineering) is pleased to organize the 6th International Conference on Advanced Power System Automation and Protection (APAP2015) in Nanjing. The theme of the conference is "Opportunities and challenges for PACS in existing and future power system". We believe that on this platform the delegates can get to know each other better, share new ideas, new technologies and new experiences, and promote progress in the industry jointly.

Strong supports from relevant parties are essential to run the conference. 268 synopses from 22 countries and regions were received, among which 174 full papers were accepted finally and published in this proceedings. We would like to thank all the bodies and individuals for your attention, support and assistance.

Relaying Protection Study Committee of CSEE

September 2015

Contents

前言

Foreword

Volume I

(1) New Development and Application of Protection

A Distinguish Method of Overload and Transmission Line Fault Based on $U_{cos\phi}$ in Voltage Plane	Huangzhang Liu, Zexin Zhou, Xingguo Wang (2)
A New Digital Relay Protection Device Using Single CPU	Wanfang Xu, Gang Xu, Qiurong Chen, Feng Gao (6)
A UHV Transmission Line Protection Based on the Multi-frequency Information	Wei Li, Xingguo Wang, Zhongqing Li, Xiao Li, Xianguo Jiang (10)
Adaptive Line Current Differential Relay for Two-Phase Transmission Line	Xiaochun Xu, Geming Liu, Qingchun Zhao, Xiaotong Zhu (16)
Advanced Arc Protection Relay as the Main Busbar Protection in the MV Switchboards of the Substation	Lin Zhou, Xinzhi Ding, and Yue Yan (21)
Coordinated Backup Protection Scheme for Smart Substation	Lin Liu, Jinghan He, Tony Yip (27)
Design of Regional Integrated Protection Hardware Platform and Software Platform	Zhanfeng Fan, Shenyi Bai, Zhiqian Bo, Guobing Song and Shengming Ge (32)
Development of Method to Detect the Permanent Fault in Transmission System based on Transient Stability	G. H. Gwon, Y. S. Oh, S. H. Sohn, H. S. Choi, D. S. Kim, C. H. Kim, and J. J. Yang (39)
High-speed and High-reliability Protection Scheme for EHV/UHV Transmission Lines in Smart Substation	Sibei Luo, Houlei Gao, Dong Wang, and Guibin Zou (43)
Impact of UPFC on Transmission Line Protection	Ning Xu, Hua Xie, Xin Yi, Qingchun Zhao, Guangwu Dai, Xiaotong Zhu, Lei Pan (50)
Influence of Current Reverse on Protection for Series Compensated Line	Xiaotong Zhu, Qingchun Zhao, Hua Xie, Jun Shen, and Zhong Wang (59)
Operation Analysis and Solution for Mal-operations of Transformer Buchholz Protection in a Transmission Utility	Jiang Yu, Hongyang Zhou, An Wen (66)
Research in the Design of Measuring and Protection Device Based on Neural Networks	Shaoliang Zhou, Li Chen, Wei Han (69)
Research of Redundancy Line-protection of Smart Substation System	Yekai Wu, Liming Su, Yuepin Zhang (75)
Research on Intelligent Protection Area Network Setting	Chunjie Li, Chenliang Pan, Liqiang Gu, Xiongli Li (80)
Research on the Effects of TCPS on the Distance Protection	

-*Zhuoran Kang, Dan Liu, Wensen Wang, and Xiaoning Kang* (84)
- Study on Fault Characteristics of Multi-send HVDC System and its Impact on Protection
*Jinping Liu, Haifeng Li, Guohao Mai, Maosheng Ding, Xiaoli Wang* (90)
- Study on LC Detuning Failure Protection for the Static Blocking Filters
*Qixue Zhang, Baoli Xu, Kai Wang, Guang Wang, Jun Chen, Xicai Zhao* (97)
- Study on the Impact of AC Protection Employed in UHV AC/DC Hybrid Power Grid
*Yi Wu, Yibin Guan, Qingchun Zhao, Yandong Zhang, and Hua Xie* (102)
- The Application of Zero-phase Digital Filter Algorithm in Transformer Differential Protection
*Chao Zhu, Xinzhi Ding and Hao Chen* (111)
- The Study of Inter-turn Protection for the SCSR's Control Winding.....*Jifeng Wen, and Pinhao Mo* (116)

(2) Substation Automation System

- A Joint Research on the Substation of the Future between Portugal and China
*Ricardo Cartaxo, Fan Chen and Fernando Matos* (122)
- A Kind of Power Quality Modeling Methods and Practice Based on the IEC 61850
*Daixin Zhang, and Quan Gu* (130)
- A Route of the Time Stamp Data Detection of Power System Based on Intelligent Substation
 Communication Physical Layer*Hong Chen, Dao nong Zhang , Xin Shu , Yubo Yuan* (134)
- A Secondary Circuit Fault Diagnosis Method Based on Probability Statistics in Smart Substation
*Liying Ge, Liu Liu, Fan Yang, Jifeng Wen* (139)
- Application of Generic Interface Conversion Device in Intelligentization Reconstruction for Busbar Protection
*Huan Ye, Fengguang Wang, An Wen, Hang Lv, Manyong Zhao, Xin Jin, Xiao Gong, Min Mou* (144)
- Application of Protection Relay Information in Substation*Fuqiang Zhou , Yutao Qiu , Danlu Xu , Weihong Hou* (150)
- Application Research about Relay Information Based on IEC 61850 Model
*Shaoqian Hu, Li Li, Zhong Qi, Qing Lin, Xiaoxiang Dai* (155)
- Enhancement on Protection Application and Automation in Distribution System
*Chun Kit Lit, Chi Hang Hau, Huibo Tu* (165)
- Evaluation of Data Flow Control Analysis and Performance for Architecture of Secondary Substation System (AS³) Design
*F. Dong, and H. Li, R. Zhang* (170)
- Fault Location and Auto-Reclose for Hybrid Lines Based on the Application of FOCT
*Jun Shen, Xiaotong Zhu, Liguang Xu, Geming Liu, Qingchun Zhao, Jun Zhao* (175)
- Field Trial of Process Bus Based Line Protection Using NCIT and CIT at Each Respective End
*Keigo Adachi, Masahiro Yamaguchi, Yasuyuki Tanaka, Tadatsune Sato* (181)
- First Meralco IEC 61850 Smart Substation— Challenges and Learnings
*V. V. Nicolas, A. A. Alagao, L. J. C. Maagma, R. A. Cullano, A. M. Abuel, Jr* (187)
- IEC 61850 Engineering Process of Multivendor Intelligent Electronic Devices for Breaker Failure Protection Scheme
*Mohd Noorfazly Noran, and Zainoren Shukri* (198)
- Research of Graphical IEC 61850 Modeling and Automatic Processing
*Yadong Feng, Guodong Wang, Hongjun Chen, Jifeng Wen, Quanrong Shen, Songlin Chen* (204)
- Research on New Type of Merging Unit for Operation and Maintenance

.....	<i>Qian Zhao, Guoming Qian, and Fufeng Chen</i>	(209)
Smart Digital Substation Deployment—Feedback on Contract Execution and In-service Experience	.....	
.....	<i>S. H. Richards, and A. Varghese</i>	(216)
The Discussion about Scheme of IED's Data Model Management in IEC 61850 SA Project	.....	
.....	<i>Xiaoxiang Dai</i>	(221)
The VLAN Based Configuration Principles of Network Load in Digital Substation	.....	
.....	<i>Yanming Ren, Xin Huang, Xi Tang, Zheng Li</i>	(224)
UML and XML Applications to Protection and Control	.....	
.....	<i>A. P. Apostolov</i>	(228)

(3) Stability Analysis and Control

A Study on Procedure of Selecting Reactive Power Compensator Location to Improve Transient Stability	.....	
.....	<i>Sungchul Hwang, Hyunwook Kim, Minhan Yoon, and Gilsoo Jang</i>	(236)
An Under-voltage and Under-frequency Load Shedding Scheme Based on State Space Graph	.....	
.....	<i>Yuehai Yu, Yuxiang Shi, Xiaochen Cai, Fenqing Wei, Hongtao Yang, Daonong Zhang</i>	(240)
Application of Stability Control System in AC-DC Hybrid Power Grid	.....	
.....	<i>Yang Bai, Dongxu Chang, Ke Xu, Shangxue Xia, Zuyi Ren</i>	(247)
China's Power System and Relay Protection Technique in Preventing Blackout for the World	.....	
.....	<i>Dingzhong Meng</i>	(252)
Development and Application of a Wide Area Response Based Power System Transient Stability		
Detection Analysis & Simulation Software	.....	
.....	<i>Jinquan Zhao, Yujie Zhang, Pan Zhang, Xiaoming Jin, Chao Fu, Hongxin Li</i>	(261)
New Frequency Estimation Solution with High Stability for Load Shedding	.....	
.....	<i>Jinlei Xing, Chenliang Xu, Lifan Yang and George Evans</i>	(267)
Power System Stabilizer Design for Multimachine Power System Using Genetic Algorithm	.....	
.....	<i>Abinet Tesfaye, J. H. Zhang, D. H. Zheng, and D. N. Zhang</i>	(274)
Research and Application of Low Frequency Oscillation Detection Device	.....	
.....	<i>Shangxue Xia, Yang Bai, Zuyi Ren, Liang Wang, Ke Xu</i>	(283)
Research and Application of Power Stability Control System in Ecuadorian State Power Grid	.....	
.....	<i>Zuyi Ren, Nan Gao, Yang Bai, Shangxue Xia, Ke Xu, Bifeng Wang</i>	(287)
Smart Load Shedding Strategy for Minimized Supply Interruption	.....	
.....	<i>Qiteng Hong, Andrew J. Roscoe, and Campbell D. Booth</i>	(293)
Systemic Protection System of Ecuadorian Power System	.....	
.....	<i>Verónica Flores S., Roberto Barba B., Gabriel Argüello R.</i>	(300)
TEPCO's Experience of Stability Problems and Development of Wide Area Special Protection		
Scheme without Telecommunication	.....	
.....	<i>T. Yasuda, Y. Suzuki, Y. Ichikawa, H. Oshida, Y. Kowada, H. Nishino</i>	(306)

(4) Wide Area Monitoring, Protection and Control

Development of a WAMS laboratory for Assessing PDC Compliance with the IEEE C37. 244 Standard	.....	
.....	<i>A. Nechifor, M. Albu, R. Hair, P. Dattaray, P. Wall, and V. Terzija</i>	(316)

Implementation of a Wide Area Monitoring Scheme for the Indian Power System	<i>Peter Harding, Ritesh Bharat, Graeme Lloyd, Abraham Varghese, Nilesh Raje</i> (321)
P Class Synchrophasors and Their Applications	<i>A. P. Apostolov</i> (331)
Research on Power Oscillation Identification in PMU	<i>Yun Wang, He Wang, Daonong Zhang, and Jian Shen</i> (338)
Synchronized Information Platform for Integrated Wide Area Protection and Control	<i>Z. Q. Bo, Q. P. Wang, B. H. Zhang, B. M. Zhang and F. Q. Zhou</i> (342)
Wide Area Monitoring and Control for Power Grid Low Frequency Oscillation Problem	<i>Bonian Shi, Zhichao Liu, and Daonong Zhang</i> (347)

(5) Protection and Control for Renewable Energy Generation

A Research on High-precision Power Forecast Method for Photovoltaic Power Station	<i>Kai Zhao, Jingtao Han, Shenqiang Wang, Yiming Wang</i> (354)
An Integrated Monitor and Control System Proposed for PV Generation Grid-connection	<i>Peng Gao, Dianfeng Wu</i> (358)
Analysis and Calculation of Short-circuit Current Contributed by Photovoltaic Generation	<i>Di Zheng, Jinxin Ouyang, Xiaofu Xiong, Chao Xiao, Ruimiao Wang, Jin Gao</i> (363)
Application in Power Plant for Active Power and Reactive Power Automatic Fast Control Based on Scaled small Hydropower Stations	<i>Yong Xiao, Jinhui Wu, Shaohua Jiao, Xiankui Wen, Gang Liu, Xiaojin Chen</i> (368)
Application of AGC/AVC in Large Grid-Connected Photovoltaic Power Station	<i>Wei Huang, Yanlei Jin, Hao Xu, Xiaoping Wang</i> (374)
Coordinated Voltage Control of a Doubly-fed Induction Generator-based Wind Power Plant Using a Voltage Change	<i>G. Park, J. Kim, Y. C. Kang</i> (378)
Fuzzy Synthetic Evaluation on Wind Farm Based on Changeable Weight AHP Considering Technical and Economic Factors	<i>Xiangying Duan, Xueying Wang, Kai Chen</i> (382)
Improvement on Special Protection System Design for Sending-end Power Grid with High Penetration of Wind Power	<i>Bonian Shi, Zhichao Liu and Daonong Zhang</i> (387)
Research on High Impedance Fault Detection in Wind Farm Collective Feeders	<i>Jiang Ni, Bin Wang, Yuanyuan Lu, Xinzhou Dong, and Daonong Zhang</i> (392)
Stepwise Inertial Control to Prevent Over-Deceleration	<i>D. Yang, J. Lee, and Y. C. Kang</i> (398)
System Design and Control for String PV Inverter	<i>Yong Li, Jingxiao Wang, Yong Guo, Gaoxiang Mi, Weiqun Liu</i> (402)
The Challenges that Distributed Energy Resources Present to Protection and Control Systems	<i>A. P. Apostolov</i> (407)
Time Function for Output Power of Photovoltaic System Based on the Influence of Micro Weather Factors	<i>Hong Li, Zizi Zhang, Yang Zhao, and Jing Zhu</i> (413)
The research on Optimization Design of DFIG Crowbar	<i>Jun Chen, Xiaofu Xiong, Rui Yu, Chao Xiao, Jinxin Ouyang, Yu Chen</i> (420)

(6) Protection and Control for HVDC

- A Novel Directional Comparison Pilot Protection for Hybrid HVDC Transmission Lines Based on Fault
Traveling Wave Energy *Yanting Wang, Baohui Zhang, and Fei Kong* (426)
- A Novel Integrated Disturbance Identification Method for ± 800 kV UHVDC Transmission Line Protection
..... *Fei Kong, Baohui Zhang, Yanting Wang* (432)
- A Realization of HVDC Grid DC Transformer Based on AC/DC Converter
..... *Peng Yang, Shicong Ma, Adapa Ram, Xu Zhang, Jing Yang and Xu Cen* (437)
- Analysis on Grounding Mode of Multi-Terminal VSC-DC Distribution System Based on Hybrid Converters
..... *Gang Sun, Bonian Shi, Yuming Zhao* (441)
- Application of Multiterminal Voltage Sourced Converter in Zhoushan Project
..... *Zhaoqing Hu, Yunlong Dong, Jie Tian, Haiying Li, Dongming Cao* (449)
- Control and Protection Sequence of an Offshore Integrated MMC MTDC System with Master-Slave/Droop
Control under Converter AC-Side Fault
..... *Puyu Wang, Xiaoping Zhang, Na Deng, Paul F. Coventry, and Ray Zhang* (454)
- Control and Protection System Design for Tripole HVDC Transmission System
..... *M. Hu, W. Bao and Z. X. Shao* (460)
- Overview of the World First Five-terminal VSC-HVDC Transmission Project
..... *Peng Gao, Zhenxia Shao, Long Xu, Dianfeng Wu* (467)
- Research on Control Strategy for MMC based DC Distribution Network
..... *Shupeng Li, Bonian Shi, Yuming Zhao, Zhenyu Xu* (473)
- Research on Islanding Mode of UHVDC and Its Operation Control Strategy
..... *Jianming Wang, Jian Zhang, Chuandong Li, Dawei Ren, Yonghua Yin* (479)
- Study on the Influence Law of AC Asymmetrical Fault on HVDC System Commutation Failure
..... *Yanting Wang, and Baohui Zhang* (484)
- Summary of UHVDC Line Fault Recovery Function and Its Practical Simulation Calculation Method
..... *Junchuan Jia, Haijing Zhou, Ji Luan, Jingzhe Tu, Qiang Yu, and Lei Yun* (491)

Volume II

(7) System Planning, Analysis, Operation and Control

- A New Dynamic Optimization Method of Voltage and Reactive Power Control Strategy for UHV System
..... *Xin Wang, Shicong Ma, Jian He, Shanshan Wang, Zeng Bing, Jian Zhang* (496)
- A New Processing Approach for Unstructured Data in Power System based on MapReduce Technology
..... *Xiaojun Li, Shaohua Jiao, Hong Cao, Liqiang Zhang, Zhenghao Gao, Yang Yi* (502)
- A Scheme to Apply Time Series Database in Energy Management System
..... *Liu Liu, Jun Du, Yandong Zhang, Biyong Liu* (507)
- A Study on Torsional Effects of Turbine-Generator Shaft System Caused by Electric Arc Furnace
..... *J. K. Park, S. J. Chung, H. S. Choi, D. S. Kim, C. H. Kim, J. J. Yang, Z. M. Radojevic* (510)
- A Template Definition Method for Relay Protection Based on EMS
..... *Kuanghua Qiao, Huaning Zhang and Mingyi He* (515)

Analysis and Research on 500kV Bus Power Imbalance in Dispatching End UHV near Zone	Mingjun Yuan, Hao Jiang, Qiang Li, Daonong Zhang (519)
Application Analysis and Improvement Measures of the Automatic Voltage Control System Based on the EMS Platform	Shimin Wu, Jiarong Sheng, Liqiang Gu, Zhong Wei, Qi Zhu (524)
Balance Control Based on Power System Self-organized Criticality	Qing He, Jianbo Guo, shicong Ma, Qun Yu (529)
City-county Unified EMS System Solutions and Comparison	Feng Zhan, Gaofeng Zhang, Zhiliang Shi, Caiyun Lu (535)
Coordinated Control Strategies for SVCs of Large Capacity	Yong Ding, Chihan Chen, Lei Zhang, Xiaoming Li and Haiyin Li (538)
Minimum Transformer Losses Based on Transformer Economic Operation and Optimized Tie-switches Placement	Boyi Zhang, and Peter. A. Crossley (543)
Multi-objective Planning of Multi-type Distributed Generation Considering Correlations	Jing Zhu, Yajing Gao, Jianpeng Liu and Zizi Zhang (550)
Perspectives for the integration of distinct data sources used in automation systems	Marco A. M. Rodrigues, Luiz C. Lima, João C. C. de Oliveira, Ayru L. de Oliveira Filho, Nivaldo Lambert, Paulo Stein and Raul B. Sollero (557)
Research for the Quality Assessment of Electric Power SCADA Based on the State Estimation	Xuri Song, Xiaochen Ma, Miao Wang, Lingxu Guo, Shunjiang Wang, Jun Wu (565)
Research on Information Integration of Smart Dispatching System Based on Model Harmonization	Siyuan Fei, Liqiang Gu, Lin Zhang, Jian Shen, Qi Zhu and Zhe Du (569)
Study of Reactive Shunt Compensation Coordination with SVC and CSR at 750kV Substation	Zhongyuan Zhao, Xiaoming Li, Qiwen Zhou, Xinbao Wang and Xicai Zhao (574)
Summary on Secure Operation Coordinate Control System for Intelligent Interactive Bulk Power System	J. Y. Luo, H. F. Li, Y. Zhang, Y. F. Jiang, C. L. Xu, Y. Zou, and L. Liu (578)
The Integrated Protect and Control System Based on Multiple Information Interaction	Yutao Qiu, Li Li, Yudong Fang, Yang Bai, Tiejun Hu (583)
The Research of Wide-area Distributed Intelligence Alarm	Zhe Zhang, Jun Li, Jian Ning, Xu Xie, Xin Shan, Yong Zhang (588)
The Study about Optimal Placement of VSC BTB HVDC Considering Fault Current Reduction and Reactive Power Compensation	Jaehyeong Lee, Changhee Han, Minhan Yoon, and Gilsoo Jang (593)
Topology Error Identification Method Based on Active Power Estimation of Switch Branch	Yi Wang, Yan Li (598)
Torsional Dynamics of Parallel Turbine Generators with Close Torsional Frequencies	Peng Zhang, Tianshu Bi (603)

(8) Distribution Automation and Microgrid

A Local Power Balancing Method of Low-voltage Network Contained Distributed Generation Based on DC Interconnection	Jinxin Ouyang, Xiaofu Xiong, Tingli Hu, Xiaoyong Zhang, Ruilin Xu, Di Zheng (610)
A Novel Technique for Fault Level Prediction in Active Distribution Networks	Hengxu Ha, Sankara Subramanian, Krishnakumar Venkataraman (617)

An Enhanced Reactive Power Sharing and Voltage Recovering Strategy for Inverter-based Distributed Generations Connected to a Microgrid	<i>Y. R. Wang, J. H. Zhang, D. H. Zheng, and D. N. Zhang</i> (622)
An Improved algorithm for fault indication information using data of zero-sequence and positive sequence in DAS	<i>H.S. Kim, J.E. Park, M.S. Choi, S.J. Lee</i> (630)
An Islanding Detection Method Based on Voltage Harmonics and Adaptive Power Disturbance	<i>Yunkun Xu, Tony Yip, Jinghan He, Zhicheng Li and Zelong Chen</i> (634)
Construction of Protection and Control System for Active Distribution Network	<i>Zhang Song</i> (640)
Multi-objective Optimization Schedule of Active Distribution System Based on Harmony Search Algorithm	<i>Fuping Yan, Jiandong Duan, Kaiyu Wang, Teng Mu, Yang Lei, Lupeng Chen</i> (644)
Relay Coordination of Highly Meshed Distribution Grids in the Presence of Volatile Infeed and Power Flow Control	<i>M. Biller and J. Jaeger</i> (650)
Research for Micro-grid Application Based on 110kV Disney Substation	<i>Yuxiang Zheng, Senior Member, Lumin Fu, Fellow, Bangpeng Xie, Haojun Xu</i> (656)
Research on the Direction of Installed CT for Distribution Automation System	<i>H.S. Kim, J. E. Park, M.S. Choi, S.J. Lee</i> (661)
Study on Control Strategy of Microgrid Hybrid Energy Storage System Based on Experts PI Control	<i>D. Wei, D. H. Zheng, D. N. Zhang and W. Zhang</i> (665)
The Research and Application of Automatic Mapping in Distribution Automation System	<i>Fangzheng Sheng, Wen Chang, Chaojie Lu, Yu Guo, Yuebin Hou</i> (671)
The Study of Supercapacitor' Transient Power Quality Improvement on Microgrid	<i>D. H. Zheng, D. N. Zhang, W. Zhang and D. Wei</i> (675)

(9) Simulation and Testing

Development of a new type real-time digital simulator.....	<i>Zhiyong Li, Yaping Li, Pengpeng Zhou, Wei Wang</i> (682)
Functional Testing of IEC 61850 Substations.....	<i>T. Schossig</i> (687)
How Should We Isolate Multifunctional IEDs for Testing in IEC 61850 Systems	<i>A. P. Apostolov</i> (692)
Innovative and Integrated Field Testing on Busbar Differential Protection	<i>C. Pritchard, F. Fink, T. Hensler, and N. Ji</i> (698)
Realization and Application of RTDS [®] Simulator for IEC 61850 Relays in China	<i>Y. Chen, D. S. Ouellette, E. Xu</i> (703)
Research on Practical Test Technology of Protection Device Based on RTDS-GTNET	<i>F. Peng, H. L. Gao, S. B. Luo, and Y. Q. Liu</i> (709)
Research on the Equivalent Circuit Modeling of Transmission Lines and Sensitivity Analysis in Electromagnetic Transient Simulation	<i>Shicong Ma, Hua Zhang, Qing He, Yanchen Yang and Zhao Yang</i> (714)
RTDS Automated Test Scripts for IEC 61850 MMS	<i>E. Xu, D. S. Ouellette, and Y. Chen</i> (719)
Simulation and Verification of System Commissioning Test for the Second 750kV Channel Project Interconnecting Xinjiang Grid with Northwest China Main Grid	<i>Xuzhi Luo, Jian Zhang, Shuanbao Niu, Bin Zheng, Junchuan Jia</i> (724)
The Approximate Equivalent Method of Reactance and Its Application in Accelerating Speed of EMTP Simulation	<i>Chuanjun Bai, Xiang Zhang</i> (729)

Whole-view Test Approach and System for Relay Protection in Smart Substation

..... *Qiaoping Chen, Zhongyang Su, Yong Huang, Wei Lu* (733)

(10) Fault Recording and Fault Location

A Fault Location Algorithm for Series Compensated Lines Based on Two-end Information

..... *Shien He, Xiaoning Kang, Zaibin Jiao, Long Zhao, Liang Lu, Rong Huang* (740)

A Novel Traveling-wave Fault Location Method for Double-circuit HVDC Transmission Lines on the Same Tower

..... *Lvxing Guo, Haifeng Li, Yingdan Qiu, Yuansheng Liang* (746)

Improvement of Fault Location Method Based on Impedance Measurement

..... *Shanshan Luo, Chenliang Xu, Libao Xu, Lifan Yang* (752)

Research on the Location of Phase to Ground Fault for Distribution Network Using Transient Signals

..... *Shicong Ma, Qing He, Jun Yi, Mian Du, Yanchen Yang and Hua Zhang* (761)

Synchronization Method for Fault Recorders of Different Substations Based on Curve Features

..... *Gang Duan, Dong Yang, Zhichao Liu, Gang Liu, Daonong Zhang* (766)

Topology-based Fault Location Method for Distribution Networks

..... *M. M. Saha, E. Rosolowski, J. Izykowski, and P. Pierz* (770)

Travelling Wave Fault Location Principle Based on Differential Output of Rogowski Coil

..... *Houlei Gao, Dong Wang, Minjiang Xiang, Guibin Zou* (777)

(11) Communication for Protection and Automation Purpose

A Smart Substation Communication Component with the Awareness Function of the Power Business

..... *Feng Deng, Yiyu Xia, and Gaofeng Zhao* (784)

Analyses and Solution of Process-Level Network Storm in Smart Substation

..... *Tianxiao Huang, Ping Liu, Chao Meng, Peiran Wang, Guangming Xin* (791)

Analysis and Testing of Model for Wireless Communications in Smart Substation

..... *Baoyin Bian, Xin Huang* (794)

Application of SIMADYN D Serial Communication Protocol in Gui-Guang HVDC Project

..... *Xiaoping Chen, Huan Chen, Peng Zhong* (799)

Application Research of a Kind of Real-time Switch System Based on PTN Architecture in Smart Substation

..... *Qiwei Du, Shuchao Fang, and Daonong Zhang* (802)

Bandwidth Calculation Method Research and Application on Digital Communication Network for Multimedia Businesses

..... *Xiande Bu, Shouyong Li, Binglin Li and Wenfeng Tian* (807)

Overview of Development and Technical Verification of Network Switch in Smart Substations

..... *Xin Huang, Wenmeng Li, Daonong Zhang, Yongfu Wang, Yuxiang Shi* (813)

Research and Analysis of Communication Networking Model in Active Distribution Power Grid

..... *Qin Li, Junli Zong, Xiaoyang He* (819)

Ring Protection System Using Packet/ Frame-based Communication

..... *Ayako Fukui, Hideaki Sugiura, Takaya Shono, Tomonori Nishida, Seiichi Kohiga, Yoshiharu Ichikawa* (826)

Study on Business and Operation Support System for IMS Services

..... *Binglin Li, Hongzhen Yang, Xiande Bu, Wenfeng Tian* (832)

The Research on Network Pressure Test Method of Relay Protection in Smart Substation

- *Yue Yu, Chunxia Zhou, Rongrong Zhan, Yanjun Li, and Zhihua Zhan* (838)
- TWACS and the Methods for Active Distribution Networks
- *Bin Shu, Tong Zhou, Daonong Zhang, Wei Li, Lu Yin, Xuenan Li, Xin Sun* (842)

(12) Condition Monitoring Availability and Reliability

- A Health Index Model Based on Data Input from Online Monitoring System for Power Transformer Asset Management
- *Tingdong Fan, Xi Tang, and Yanming Ren* (848)
- A Novel Method for Condition Monitoring of MOA in Smart Substation
- *Xi Tang, Yanming Ren and Tingdong Fan* (855)
- Application of the Principal Component Analysis and Cluster Analysis in Comprehensive Evaluation of Thermal Power Units
- *Liqun Shang, Shoupeng Wang* (859)
- Based on Comprehensive Analysis of Electro-Acoustic Multidimensional Signal Transformer Discharge Pattern Recognition
- *Yong Wang, Shiming Li, Xiaqin Chang, Changkai Zhang, Hengxun Su* (865)
- Cable Fault Detection (CFD) System Employing Remote Terminals without DC Power Supply Using Digital Communication over Optical Fibers
- *S. Tanaka, M. Okai, H. Sugiura, T. Mori, K. Motoyama, H. Soejima, K. Iihoshi* (870)
- Continuous Trip Coil Monitoring
- *Gajendiran Balakrishnan, Xia Yang, Yongyue Ma, Hengxu Ha, Krishnakumar Venkataraman, Simon Richards* (878)
- Improvement to Conditional Reliability Coherency by Compromising Availabilities of Primary Equipments and Relay Protections
- *Shaofeng Liu, Shenghu Li, Bijun Li, and Yongjie Fang* (884)
- Research on Transformer Failure Prediction and Fault Diagnosis Based on GM-BP and PNN
- *Yaoye Zhu* (890)
- Online Monitoring Information System Based on IEC 61850 Subscription and Publishing Method
- *Wei Wang, Xianyan Pang, Liping Wang, Xiangfei Yang, Dapeng Li* (894)
- Operational Reliability Assessment of Protection System Based on Semi-Markov Model
- *Zhihui Dai, and Tianyu Zhang* (898)
- Power Equipment Risk Management Based on Refined Meteorological Information
- *Xiaofu Xiong, Jian Wang, Shijie Weng, Zhe Li, and Yun Liang* (902)
- Research of Online Protection Operation Evaluation System and Framework
- *Zhihui Dai, Xuan Liu, and Yanjun Jiao* (907)
- Research on Online Secondary Circuit Monitoring for Smart Substation
- *Jun Chen, Yong Liu, Kaipeng Bao, Rui Yu, Yu Chen* (913)
- Research on Secondary Equipment Monitoring and Analysis Model Based on CIM
- *Chao Sun, Dehe Liu, Zhixue Zhang, and Wenkai Ai* (918)
- Research on the Technology and Application of Station Level Online Monitoring of Smart Substation
- *Bo Li, Yu Xi, Tian Chen, Zexiang Cai* (922)
- Study and Application about Maintenance Strategy of Power Transformer Based on Multidimensional Information
- *Leiyuan Wei, Zhiyong Niu, Shenqiang Wang, Jingtao Han* (928)

(13) Auxiliary Power Supply

An Intelligent Load Control Scheme Based on IEC 61850 for Auxiliary Power System of Hydropower Plant	.....	Lingling Zhang, Wei Hou, Yong Shi, Wei Yan, Jun Chen (934)
Analysis and Solutions of Low Voltage Ride Through of Power Plant Auxiliary Machines	.....	Wenbo Chen, Li Wang, Zhonghua Mei, Bao Zhang, Jianfeng Mi (940)
Analysis of an HVDC Converter Station Forced Blocking Accident and Improvement Measures	.....	Yelu Tu, Rui Zhu, Li Wang, Xinxiang Wang (943)
Analysis of Ground Fault in DC System and Exploration to the Countermeasures	.....	Bingwei Yu, Li Wang, and Wenbo Chen (947)
Analysis, Countermeasures and Improvement Measures of Battery Pack Accident in Substation or Power-plant	.....	Dong Chen, Xianzhang Wu, Jian Chen, Jianguo Tan, Guobin Zhong (951)
Overview and Application of Treatment Technology for Low Voltage Ride Through Capacity of the Coal Feeder in Thermal Power Plant	.....	Yujun Sun, Yujun Yin, Liubao Ding (955)
Reliability Evaluation of Substation DC System	.....	Xiaoming Huang, Qingfang Si, Tao Yang, Xidong Xu (959)
Research and Development of Active Ground Protection Device for DC System	.....	Xiaoming Huang, Tao Yang, Xueyi Zou, Li Wang (962)
Study on DC System Based on Intrinsic Safety Design	.....	Li Wang, Xueyi Zou, and Wenbo Chen (968)
Appendix	.....	(973)

(7) System Planning, Analysis, Operation and Control

A New Dynamic Optimization Method of Voltage and Reactive Power Control Strategy for UHV System

Xin Wang, Shicong Ma, Jian He, Shanshan Wang, Zeng Bing, Jian Zhang

Abstract--With the rapid development of electric power demand, a national wide and interconnected power grid based on ultra high voltage (UHV) technology is formed in China to improve further utilization of fossil and other renewable energy. The fluctuation of transmission power on UHV line, which is caused by uncertain power output of renewable energy or outages of main power plant, needs reactive power optimization and voltage control to ensure system safe and stable. From the time dimension, the dynamic optimization method is used to switch on/off the low voltage capacitors or reactors to reduce the traversing reactive power in this paper. At the same time, the voltage of UHV line is dispatched to meet the demand of reactive power in the maximal degree. Finally, a simplified mathematical model of UHV grid is adopted to illustrate the proposed method. The simulation results showed that the DPM can effectively solve the sequential reactive power optimization problem.

Index Terms--Dynamic optimization Method, Reactive power, Renewable energy, Ultra high voltage (UHV), Voltage control

I. INTRODUCTION

WITH the rapid development of economic society and electric power demand, the ultra high voltage (UHV) grid has been formed in China to improve further utilization of fossil, hydro, wind, solar energy and other resources, which ensures the optimal allocation of electric energy across the country. However, the random and intermittent characteristics of renewable energy integrated to system cause the fluctuation of transmission power on UHV line and bring new threats to system operation. Thus, the reactive power optimization and voltage control of UHV grid has been widely concerned in system planning and operation [1], [2].

The reactive power optimization is a typical nonlinear problem, which synchronously has the continuous variables and discrete variables. There is already a rich literature to utilize the optimal power flow and global optimization algorithms to dispatch the reactive power, which ignores the time behavior of power system [3], [4], i. e. the traditional day-ahead operation schedule only focuses on the optimal allocation of reactive power for each time interval, and lacks attention to the overall optimization for the whole research horizon. Thus, the dynamic programming method is used to optimize the operation and control sequence of reactive power compensation devices and line voltage in this paper.

Dynamic programming is an effective tool to solve the optimal problem on multistep decision process, where a multistep process is converted into a series of single stage problems. The dynamic programming has been widely used in power system analysis, e. g. power system stability enhancement [5], [6], system reliability and planning [7]. Especially in reactive power optimization, a dynamic programming approach is presented to find a proper dispatching schedule for the shunt capacitors in a distribution substation as well as on distribution feeders in [8]. Considering the overall economy of power system operation, the dynamic programming is adopted to optimize the reactive power on UHV transmission lines for 24 hours a day.

The fluctuation of active power on UHV transmission lines causes wide variation of reactive power, which brings a great burden on the reactive power balance and voltage control. In the practical engineering, the fixed shunt reactors are installed on the high voltage side to compensate the charging power. According to the transmission power, the shunt reactors and capacitors on the low voltage side should be switched on/off to reduce the traversing reactive power [9].

In the present study, we investigate the sequential reactive power compensation schemes of UHV grid to ensure the overall traversing reactive power minimum. First, a mathematical model of UHV transmission line is introduced. Based on this model, a numerical method is presented to calculate the reactive power loss and compensation amount. Secondly, we propose a time-series reactive power optimization model, where the number of shunt low voltage capacitors / reactors and line voltage are considered as control variables. Finally, the dynamic programming is used to solve the proposed time-series optimal problem.

The remaining part of this paper is organized as follows. Section II introduces the power model of UHV transmission line. Section III describes the proposed time-series reactive power optimization model. Case studies are discussed in Section IV. Conclusions are drawn in Section V.

II. TRAVERSING REACTIVE POWER

A. Reactive Power and Voltage Characteristics

Since the unit resistance is far smaller than the unit reactance, the UHV grid can be considered as lossless line [10]. The equivalent circuit of UHV transmission line is illustrated in Fig. 1.

The voltage and current equations of lossless line can be formulated as