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Electrical Generation and Distribution Systems and Power Quality Disturbances

ISAK OLSEN

Electricity generation is the first process in the delivery of electricity to consumers. The fundamental principles of electricity generation were discovered during the 1820s and early 1830s by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet. Before Michael Faraday had discovered his famous law of electromagnetic induction, battery were the only source of electric power. After that, DC generator was developed, but it could produce only a few hundred volts of electric power and naturally this low voltage power could not transmitted efficiently to a large distance. In the latter half of eighteen centuries, AC electric power generation, transmission and distribution came into the picture. In an AC system, it became possible to step up voltage of electric power to desired level for efficient transmission to a long distance. After that 3-phase induction motor was developed which was much simpler in construction. Generation, transmission and distribution of AC power were much easier than DC power; hence very fast AC power system became the most popular means of electric power. Electricity is most often generated at a power station by electromechanical generators, primarily driven by heat engines fueled by chemical combustion or nuclear fission but also by other means such as the kinetic energy of flowing water and wind. Other energy sources include solar photovoltaics and geothermal power and electrochemical batteries. Additionally, the presence of a static converter as output interface of the generating plants introduces voltage and current harmonics into the electrical system that negatively affect system power quality. By integrating distributed power generation systems closed to the loads in the electric grid, we can eliminate the need to transfer energy over long distances through the electric grid. This book, Electrical Generation and Distribution Systems and Power Quality Disturbances, reveals the different power generation and distribution systems with an analysis of some types of existing disturbances and a study of different industrial applications such as battery charges.

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Preface

Electricity generation is the first process in the delivery of electricity to consumers. The fundamental principles of electricity generation were discovered during the 1820s and early 1830s by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet. Before Michael Faraday had discovered his famous law of electromagnetic induction, battery were the only source of electric power. After that, DC generator was developed, but it could produce only a few hundred volts of electric power and naturally this low voltage power could not transmitted efficiently to a large distance. In the latter half of eighteen centuries, AC electric power generation, transmission and distribution came into the picture. In an AC system, it became possible to step up voltage of electric power to desire level for efficient transmission to a long distance. After that 3-phase induction motor was developed which was much simpler in construction. Generation, transmission and distribution of AC power were much easier than DC power; hence very fast AC power system became the most popular means of electric power. Electricity is most often generated at a power station by electromechanical generators, primarily driven by heat engines fueled by chemical combustion or nuclear fission but also by other means such as the kinetic energy of flowing water and wind. Other energy sources include solar photovoltaics and geothermal power and electrochemical batteries. Additionally, the presence of a static converter as output interface of the generating plants introduces voltage and current harmonics into the electrical system that negatively affect system power quality. By integrating distributed power generation systems closed to the loads in the electric grid, we can eliminate the need to transfer energy over long distances through the electric grid. This book, Electrical Generation and Distribution Systems and Power Quality Disturbances, reveals the different power generation and distribution systems with an analysis of some types of existing disturbances and a study of different industrial applications such as battery charges.

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CHAPTER 1

Integrated Coordinated Optimization Control of Automatic Generation Control and Automatic Voltage Control in Regional Power Grids

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ABSTRACT

Automatic Generation Control (AGC) and Automatic Voltage Control (AVC) are key approaches to frequency and voltage regulation in power systems. However, based on the assumption of decoupling of active and reactive power control, the existing AGC and AVC systems work independently without any coordination. In this paper, a concept and method of hybrid control is introduced to set up an Integrated Coordinated Optimization Control (ICOC) system for AGC and AVC.

Concerning the diversity of control devices and the characteristics of discrete control interaction with a continuously operating power system, the ICOC system is designed in a hierarchical structure and driven by security, quality and economic events, consequently reducing optimization complexity and realizing multi-target quasi-optimization. In addition, an innovative model of Loss Minimization Control (LMC) taking into consideration active and reactive power regulation is proposed to achieve a substantial reduction in network losses and a cross iterative method for AGC and AVC instructions is also presented to decrease negative interference between control systems. The ICOC system has already been put into practice in some provincial regional power grids in China. Open-looping operation tests have proved the validity of the presented control strategies.

KEYWORDS

Integrated Coordinated Optimization Control (ICOC); Automatic Generation Control (AGC); Automatic Voltage Control (AVC); discrete event-driven; hierarchical control; cross iterative calculation

1. INTRODUCTION

Automatic Generation Control (AGC) and Automatic Voltage Control (AVC) systems are crucial parts in a modern Energy Management System (EMS). Active power dispatch and frequency regulation in China consists of three parts: Economic Dispatch Control (EDC) ahead of day, Load Frequency Control (LFC) and Primary Frequency Regulation (PFR) for real time. EDC is formulated to satisfy the hourly load demand based on load prediction ahead of day; LFC is responsible for frequency volatility with cycles ranging from 10 seconds to several minutes, while PFR deals with the real time balance of generation and load [1]. LFC is implemented by an AGC system, and in recent years integrated EDC/AGC systems have been widely used and are regarded as the standard AGC system. On the other hand, since several blackouts took place in the world's large power grids due to voltage instability and collapse, voltage stability and control has attracted worldwide attention among researchers and industrial professionals, with a number of significant achievements being made [2,3]. One of them is the hierarchical voltage control model, which can effectively prevent voltage collapse through optimization of reactive power distribution. The hierarchical model has laid the foundation of the AVC system. It should be noted that due to the physically weak coupling between *P* and *Q* [4], the existing AGC and AVC systems work independently without interaction or coordination. However, the separate optimization method is unreasonable in the following aspects:

- Active and reactive power regulation are both constrained by the generator capacity limit, so separate optimization is not able to guarantee that the generator is operating in the secure zone;
- Line loss is part of the active power output, but the conventional Loss Minimization Control (LMC) model only considers reactive power optimization. From the perspective of economical operation, the active and reactive optimization should not be separated;
- Active power/frequency control and reactive power/voltage control are not completely decoupled even under normal conditions, for example, frequent fluctuation of active power affects the voltage quality; interactions between AGC and AVC control commands result in weakened control effects and reciprocal regulation. Furthermore, the weak coupling relation no longer exists in overload conditions and the independent control model may cause security problems.
- Recently, with the increasing penetration of wind power energy, its impact on power system operations cannot be neglected. Wind generation operation requires a large amount of reactive power support and flexible frequency regulation ability, hence putting higher demands on AGC and AVC systems, especially for the cascading trip-off accident tangling with active and reactive power control at the same time [5].

With the development of information and automatic control technologies, coordinated control of active and reactive power is recognized as a major trend. This is also in line with the integration concept in smart grids, with all smart devices and control systems taken into consideration [6].

To date, research on coordination of active and reactive power is largely unreported. In [7] a new dynamic power flow algorithm was proposed, which helps avoid unreasonable power flow distribution due to bus type definition through joint adjustment of active and reactive power. Concerning economically coordinated dispatch, in [8], an active/reactive coordinated optimization model is set up to allocate network losses to each generator under the principle of minimizing total generation cost, but in dealing with conflicting inequality constraints, the converting bus and branch type methods proposed in this paper may cause frequent transformation and affect convergence of the algorithm. Other research is based on prediction control. Through ultra-short load forecasting, active/reactive power flow can be optimized to minimize network losses and maximize loading margin [9,10], yet real-time coordinated control is not involved. Currently all relevant research is largely in the theoretical exploration phase, without reports about AGC and AVC coordination in the engineering field.

The concept and control strategy of an Integrated Coordinated Optimization Control (ICOC) system for AGC and AVC is introduced in this paper from an engineering perspective. The ICOC system is designed in a hierarchical structure with respective targets and control objects for each layer. In the top layer, three types of discrete events, regarding security, quality and economic events, are defined to drive the responding joint optimization block. The hierarchical control and event-driven mechanism significantly reduce the complexity of the multi-target optimization problem concerning diverse control devices. Meanwhile an innovative LMC model adopting both active and reactive power regulation is proposed to substantially reduce network losses. In addition, to minimize the negative interaction between AGC and AVC commands and improve operation quality, an instruction cross iterative method is also presented. Based on the control framework and strategies mentioned, practical ICOC systems have already been established and open-looping control tests conducted in some regional power grids in China. Pre-operation of ICOC proves the validity of the presented control strategies. The remainder of this paper is structured as follows: Section 2 describes the system structure and control model of the proposed ICOC system. Section 3 gives the detailed design proposal of a practical ICOC system according to the technical conditions of a provincial power grid. Section 4 demonstrates the single section and continuous simulation results of the ICOC system, and analysis of the advantages of coordinated control. Section 5 concludes this paper by summarizing the unique characteristics and significance of ICOC system.

2. SYSTEM STRUCTURE AND CONTROL MODEL OF ICOC

The ICOC system adopts the discrete event-driven pattern and hierarchical structure from the concept of hybrid control theory [11]. ICOC takes into account the coupling relation between active power/frequency and reactive power/voltage, integrating the original optimal indices and modifying the conventional algorithms. By making full use of control resources, the ICOC system is able to improve system stability, operation quality and economy. The hierarchical structure of the ICOC system is shown in Figure 1.

The ICOC system consists of three layers: Top Layer for Management and Decision, Middle Layer for Coordination and Bottom Layer for Execution. Each layer is designed with its own responsibilities, including receiving control targets from the upper layer, performing optimization calculations, as well as forming instructions and sending them to the lower layer. Overall regulation in a hierarchical approach is thus carried out, helping to achieve an integrated optimal target as expected.

2.1. Top Layer for Management and Decision

The Top Layer for Management and Decision, which monitors the operational status of the power system through Supervisory Control and Data Acquisition (SCADA) and Wide Area Measurement System (WAMS), analyzes the security, quality and economic status to judge whether the system is under optimal or quasi-optimal conditions. Once any index exceeds its limits, an event will be formed to drive a responding control block, which then works out commands and sends them to the Middle Layer.

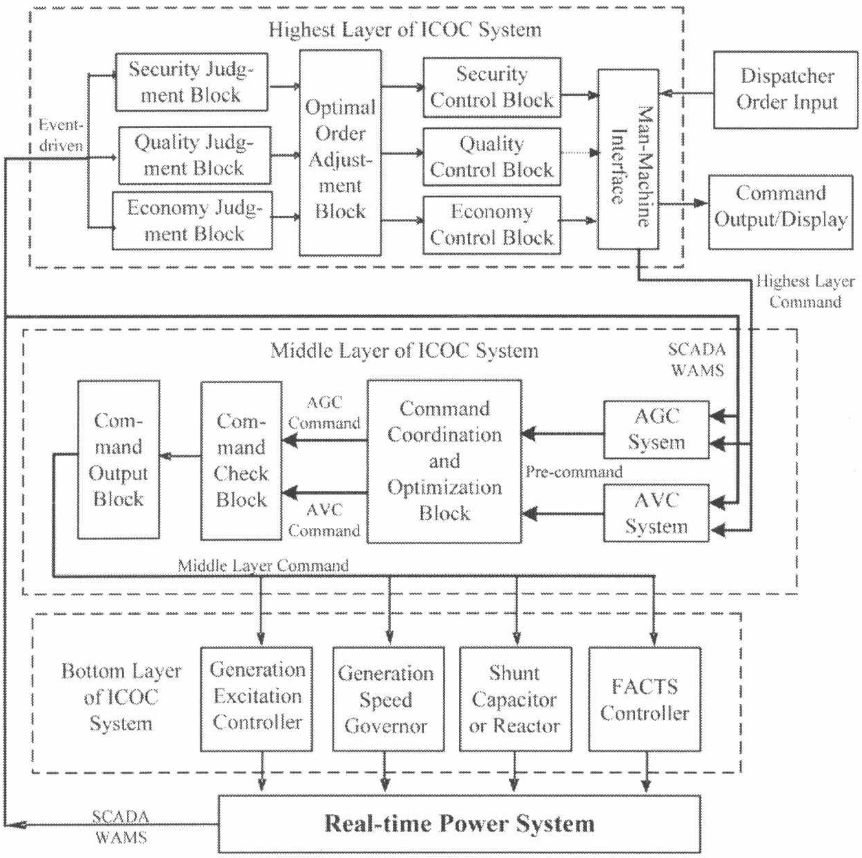

Figure 1. Hierarchical structure of the ICOC system.

2.1.1. Economic Event and Control Model

The economic event monitors the network losses and can be defined as follows:

$$E_{eco} = \begin{cases} C_{econ} & \text{if } P_{loss}[\mathrm{k}] > P_{loss-eco} \\ C_{enon} & \text{if } P_{loss}[\mathrm{k}] \le P_{loss-eco} \end{cases} \tag{1}$$