Retrospect and Prospect of NARI Generator Excitation System

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***Abstract*—In this paper the development and achievements of NARI generator excitation system were introduced, and the main design features were discussed. With the development of today's electric power system toward smart grid and smart power station/plant, the modern excitation system should provide support for this change, and the trends of excitation system development were highlighted.**

Keywords-smart grid, smart plant, excitation system, low frequency oscillation,sub-synchoronous oscillation

I. INTRODUCTION

In recent years with the technology development, the control strategy is increasingly sophisticated, the functions of automatic control device are constantly expanding, and the performance is constantly improving. As an automatic control device, the generator excitation system is no exception. The functions of the excitation system evolves from its basic functions of maintaining the generator terminal voltage，distributing reactive power among generator units [1], to protecting the generator against abnormal operation beyond its capacity using different types of limiters [2], and to further development into increased support for the security and stability of the power system, such as using power system stabilizer (PSS) to curb the low frequency oscillations (LFO) and other additional features [3, 4]. Many functions of the generator excitation system are no longer merely to satisfy the safe and stable operation of the power plant, but to enhance the transient stability of the power grid, and to provide support for the dynamic stability and static transmission capacity.

With the rapid increase of installed generator capacity and power grid interconnection, the size of the Chinese power grid is getting larger and larger, thus power grid security and stability issues become increasingly prominent. Although the generator excitation system cannot completely solve these problems result from long-distance transmission and grid scale increase, it after all, is the most direct and economical and most effective means to them. Therefore, in recent years, there have been a lot of requirements to the generator excitation system from the perspective of the grid. Power plant management will gradually move to the real time control system such as excitation control for extending the functionality and performance.

As one of the earliest enterprises engaged in research and development of microcomputer type excitation system, NARI continues to upgrade its products through innovation, and its product quality and performance are comparable to well-known international companies, its domestic market share increases steadily, and has entered the international market.

II. NARI EXCITATION SYSTEM DEVELOPMENT AND ACHIEVEMENTS

Along with the development of China's power industry, NARI excitation system has experienced more than 30 years of continuous development, which can be divided into the following four stages.

A. Stage I: Initial product research and development.

Starting from the end of 1979, the automatic voltage regulator (AVR) research group was set up within the automatic control department in the then Ministry of Electric Power, Nanjing Automation Research Institute (NARI). A strategic plan was to abandon the analog type AVR for the excitation system, and directly develop microprocessor-based AVR. This research proposal was approved by the Ministry Science and Technology Department as a Seven-Five-Year research project. After several years of research, in July 1984 NARI Electrical Control Sub-Company developed the first industrial prototype. Followed by preparation of a variety of adjustment and limiter software, as well as all kinds of tests, the sample AVR was transported to the Chitan Hydropower Station in February, 1985. It was installed on the 50 MW generator of Unit 2. Site commissioning began in early April, and after a series of tests, on April 27 the excitation system passed the 72-hour trial test and was officially put into service. It won the First-Prize of Science and Technology Progress Award of the Ministry of Electric Power of China in 1986 and the Third-Prize of National Science and Technology Progress Award in 1987 by the National Science and Technology Commission of China.

B. Stage II: Product promotion and function development

After the successful launch of the NARI microcomputer type AVR, we started the product promotion. Typical projects include: 1989 Gezhouba Second River Hydropower

Station (on the Changjiang River, the longest river in China) 3×170MW turbine generator excitation system upgrade, the regulator has withstood the test of accident conditions; 1991 Longyangxia Hydropower Station (on the Yellow River, the second longest river in China) 4 × 320MW turbine generator excitation system upgrade; 1994 Tieling Power Plant 300MW steam turbine generator excitation system upgrade and Xuzhou Power Plant 2 × 200MW AVR upgrade.

In 1996 we developed China's first all-digital adaptive power system stabilizer (PSS). In 1998, the first domestic developed static thyristor excitation system was developed for 300MW generator. In 1999, we successfully developed a new generation SAVR-2000 type AVR.

C. *Stage III: Upgrade of famous manufacturers' excitation systems*

In 2000 we upgraded GE excitation system with self shunt excitation system for the 660MW turbine generator in Yangzhou No. 2 Power Plant. In 2003 we upgraded two Russian excitation system of two 800MW coal-fired power plant excitation system. We also upgraded the excitation systems of world famous companies like Mitsubishi, Rolls-Royce, SIEMENS, ABB, ALSTOM and other well-known manufacturers. In 2004 we won the contract of providing 12 sets of excitation system for the 700MW units of Three Gorges Right Bank Power Station, the world's largest hydropower generating station.

D. *Stage IV: Major breakthrough*

In 2007 the first set with completely independent intellectual property rights of 1000 MW class sample generator excitation system was successfully put into operation in Yangzhou No.2 Power Plant, the AVR is a new generation NES5100 type. In 2009 the first home-made 1000MW excitation system for thermal power plant was put to use in Suizhong Guohua Power Company Limited. In 2011 we won the contract of providing two sets 1000 MW brushless generator excitation systems to Tianwan Nuclear Power Station.

In 2012, we successfully developed a new generation NES6100 type AVR. It is the first domestic set to meet the demand for IEC61850 communication protocol; has IRIG-B time code and GPS time interfaces; possesses SOE function to facilitate the fault analysis; uses Clark, Parker transform for instantaneous sampling; uses LINUX operating system for interactive interface; has many variable and flexible test access, and special debugging tools as technical support for wide area power system stability control. The NES6100 type AVR has significant enhancement of EMC, ambient temperature, and anti-vibration performance of hardware, which further strengthens its reliability.

III. Design Features of NARI Large Generator Excitation System

Over the years NARI is striving to develop its excitation products based on technological progress and innovation, and the accumulation of technology and field experience, as well as in-depth understanding of customer needs. We further lifted the performance of our products, improved the system reliability through listening to expert advice and recommendations, implementing large projects, and co-operating with world-class excitation system manufacturers. All these efforts made our products become the industry leader and shaped our design style of the excitation system.

NARI's large generator excitation system design follows the following principles:

A. *Reliability principle*

1) New technology application creteria: Put mature new technology into excitation system is an effective method to lift the excitation system's technical level, expand its functions and enhance its performance. But when adopt every new technology, the technology must be evaluated, tested and appraised.

2) Design simplification criteria: Reliability increases when simplified. Use the simplest possible circuit and structure as long as the function is not impaired.

3) Redundant and fault-tolerant design: For key components or links redundant design is used; for occasions where signal errors can lead to serious consequences fault-tolerant design is used. Take measures to avoid control system abnormalities caused by device quality or signal transmission quality.

4) Thermal design criteria: Accurate and presice calculation of the thermal design prevents the device from unexpected thermal aging which may affect the system's designed life. Under specified dissipate power consumption, make full use of the structure, material and aerodynamic characteristics.

5) device selection criteria: Selection of component device is in strict accordance with the reliability requirements.

6) derating design criteria: Improve the reliability of key components by increasing the capacity margin.

7) EMC design criteria: Adopt various shielding and grounding measures to ensure the system satisfies EMC requirements.

8) Tolerance design criteria: Minimize the effects of temperature and changes in the operating point to the device characteristics.

9) Stability design criteria: Leave sufficient margins in the product design.

B. *Systematic design principle*

1) Consider of all relevant parameters of generator sets and power system requirements to the excitation system, determine the overall excitation system scheme.

2) Take the excitation system as a whole to design, and do precise calculation and simulation for key components. Avoid isolated design of single component, which may result in overall system performance deviation or even substantial decline.

3) Consider the coordination of the various components within the system, make full use of the redundancy of components and improve the overall system reliability.

4) Strict sequential design, give full play to the various components of interoperability, minimize non-steady-state operation on critical components within the system, and to extend the service life of the system.

C. Standarized design priciple

Maximize the inheritance and use mature standardized design for standard function module. For innovative work, strictly implement standardized processes and minimize the risk of falling reliability when using new technology to improve performance and functionality.

IV. NARI EXCITATION TECHNOLOGY DEVELOPMENT PRIORITIES UNDER SMART GRID AND SMART STATION

With the development of smart grid and smart power station, large-scale new energy access, large regional grid interconnection, long distance ultra-high voltage transmission, unattended smart power station, etc., it is required that the generator excitation system has the following technical characteristics:

A. Excitation control for large pumped storage unit:

Recent years due to the rapid development of wind power, solar power and nuclear power in China, grid access poses great difficulty. For grid security and stability, the most effective way is to build pumped storage power stations to absorb random and intermittent wind power, solar power and difficult-to-regulate nuclear power.

Large pumped storage power station has the functions of load leveling, frequency modulation, phase modulation, emergency reserve, flood prevention and anti-drought. It has the advantages of flexible operation, quick response, and plays an important role in improving power system load leveling, ensuring the safe and stable economic operation of the power system.

For large pumped storage excitation control technology, these aspects are focused: in-depth analysis of the effects of the excitation system to the grid security and stability; excitation control strategy and key technology in the load leveling; complementarities between nuclear and water power, wind power and water power; excitation control strategy during different starting modes like SFC start, back-to-back start, black start and during rapid conversion of working conditions; excitation model and parameter configuration for system security and stability calculations; study of large pumped storage unit excitation system design and development techniques; study of large pumped storage excitation control system specification. Especially the various startup mode control strategy is of great significance for achieving intelligent scheduling, automation and interaction.

B. Excitation control for low-requency oscillation prediction and restraint

As the regional power grids interconnected, the frequency of low frequency oscillation is getting increasingly lower and the frequency band is getting increasingly wider, ranging from 0.2 Hz to 2.5 Hz. The present PSS model and parameters in operation often do not provide sufficient positive damping in the lower frequency range. So with the increase of grid scale, further research is needed to PSS which is able to generate sufficient positive damping effect in a wider frequency range, such as PSS4B [5]. At the same time, a variety of information should be used to predict the low frequency oscillation and the state of the grid, in order to avoid the not-in-good-state device operates with high load, and to take opportunities to eliminate the defects, avoiding low frequency oscillation caused by exit of those devices.

With the development of PMU technology [6] and stability control technology, it is possible to observe the state of the grid from a broader perspective. This makes it possible for us to utilize the unit capacity, improve system stability. So it is necessary to study the wide area PSS technology, through the PMU or stability control device, to send different point grid information to the excitation system, and according to certain control strategy, enhance the system damping and curb the low-frequency oscillation.

C. Coordinated excitation control for group units

For group units with different geological and electrical locations, the coordinated control technologies and strategies are studied on exchange of information like generator status and operation parameters, to achieve inter-group unit coordinated control of the excitation system, including coordinated control of the sending end units of UHV AC and DC power transmission, control of unit groups with converter station, and tap on the power system stability, maximize transmission capacity, and to achieve unit group optimal excitation. Study is also carried out on analysis of the role of excitation on power system steady-state, dynamic state as well as the control model and control strategy between unit groups.

D. Integrated and coordinated control of excitation and governor

By analyzing the control characteristics of the excitation system and the governor system and the requirements of PSS and system frequency modulation, research is carried out on the integrated control of excitation system and governor, the coordination of excitation side PSS and governor side GPSS, theory for PSS innovation, and new technology of excitation, governor, and PSS to adapt to the development of UHV power grid. The purpose of this study is to optimize the overall coordination between excitation control and speed control to improve power system dynamic characteristics, and further improve grid stability and power transmission capacity.

E. Excitation control technology for smart station

As the core of the generator control system, the technical development of the excitation system plays an important role to support the smart station. To further enhance grid security and stability level, it is needed to promote the role the excitation control technology plays to improve smart station security and reliability.

The smart station is based on the power plant equipment as well as various intelligent automation components. In recent decades microcomputer based control system is widely used, the degree of automation of devices has increased substantially, microprocessor-based excitation regulation and protection have been widely used, and PSS has achieved good results to curb the grid frequency oscillation.

With the development of control and computer technology, the generator excitation system, in addition to maintain the generator terminal voltage of its basic function, has played an increasingly important role in the stability of the grid. Excitation system redundancy and fault tolerant design, self-diagnosis and appropriate auxiliary loop control model and the choice of parameters, the main loop and auxiliary loop coordination have become important means to make the excitation system smart. To cope with the smart station, the excitation system research and development need to focus on the following:

1) Redundant fault-tolerant design and self-diagnosis: The smart station requires that the excitation system in additin to have the normal AVR, limitation, warning and other basic functions, be able to judge correctly with the interface status of the devices based on the status information to form an abnormal or failure control strategy, which requires the excitation system design to use a large number of redundant fault-tolerant technology. It also minimizes the reliability requirement of the equipment, meaning that when interface device or component part failure or malfunction occurs, the excitation system can still maintain fault-tolerant operation. While the excitation system also need to have self-diagnostic function, that is, when the excitation system of non-core component fails, the faulty components can be repaired (self-healing) or excluded from the regulation, and issue correct fault diagnosis information to help locate the fault and to assist plant personnel to maintain normal operation.

2) Coordinated control between different control strategies: So far, research on the effects of grid fault or generator internal malfunction to the excitation system are still not mature, the control strategy under above situations has yet to be studied in depth, especially the coordination of under excitation with PSS control, coordination of PSS between different power stations, and the coordination between different sub-systems.

3) Coorinated control between units within the same power station: The smart station is not just smart control of one single unit, but smart control between units of the whole station. So the smart station excitation system must first be able to get information of other units and the entire plant, so that it can adjust its behavier. Therefore, the excitation system must have powerful communication ability to meet the requirements of information exchange. Meanwhile the smart station excitation system needs to have automatic decision-making capabilities according to its own needs as well as the status of other units within the station to adjust its behavior in order to maximize the role of the entire plant on the grid, and to achieve maxim efficiency of the whole station while providing the most powerful support to the grid.

V. Conclusion

Through more than 30 years of continuous development of microcomputer based generator excitation system, NARI products now cover wide range of applications, from hydro, thermal, nuclear to pumped storage. We have upgraded excitation systems of various world famous manufacturers. With the development of strong and smart grid, smart station, our research and development focus on this trend, our new generation excitation system has provided communication interfaces to accommodate this trend and we will continue our effort to meet the needs of our customers.

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