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Coding embedded hybrid switching fabric applications in next generation power system backbone

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ABSTRACT

With the advent of the new information technologies, the power communication service object is continuously improved by the modernization level of the electric power industry. The long term planning goal is not only to provide a transmission pipeline of power dispatching, but also a variety of service type, which requires a reliable and high efficiency power system communication network. Previous researches on the wide area protection propose a feasible solution on adaptive protection by using IP/SDH-based WAN. With the increasing capacity requirement, tradition IP/SDH device will be replaced gradually by the optical transport network. In this paper, we propose a novel hybrid switching fabric reconfigurable optical add-drop multiplexer/optical cross-connect (ROADM/OXC) by using electric coding embedded approach on the high speed backbone router. Also, the corresponding hybrid switching network coding (HSNC) scheme is propose to implement real-time cross-connect operation. HSNC schemes are integrated with MAWAPS of previous research and the results show that it is an efficient approach for various granularities switching structure. Performance of HSNC under different switching ratio and fiber core is presented and is also compared with traditional approach, and it is concluded to be a competitive approach that can be widely used in the next generation power grid backbone.

1. Introduction

The world is carrying out a large number of activities to upgrade the power grid, so that the electric power system can work under a more efficient, reliable and economic way, including upgrade of power generation, transmission, distribution and measuring instruments. An important aspect of these upgrades is to improve communication abilities in a variety of monitoring and metering equipment and therefore achieve intelligent and reliable information and communication technology (ICT) network of power grid [1]. The up-to-date ICT infrastructures are drawing increasing attentions with the growing power requirement due to the rising energy cost and rapid developed grid system [2]. Packet optical transport network (P-OTN) is intended to build a transition communication network on current ROADM technology to enable next-generation colorless, directionless and contention less (CDC) networks [3]. The concept of smart grid combines traditional power technology with modern information and communication technology and makes it possible to provide energy and information services simultaneously. Smart grid is commonly regarded as a power system that can incorporate millions of sensors that all connected through an advanced communication and data acquisition system. This system will provide real-time analysis by distributed computing system that will enable predictive rather than reactive responses to sudden disruptions. An integrated, two-way communications and networking platform is essential to the smart grid [4]. The electric power dispatching automation system can be commonly divided into three categories, i.e., responsive protocol (SC1801, U4F, ModBus, etc.), circulating protocol (CDT, DXF5, C01) and peer-to-peer protocol (DNP3.0). There are also different requirements for different types of substation automation system communication network, RS-485 or FieldBus are widely used in 35 kV substation network within the substation. FieldBus and Ethernet can be used as data communication for bay level device, while ProfiBus or fiber network is desired at 220–500 kV extra high voltage substations. There are various types of substation automation system transmission protocol, which lead to a system interconnectivity and interoperability problems. The IEC 61850 promulgation and implementation of substation automation system from the process layer to the control center will use a unified communication protocol [5,6,8]. Telecontrol is the basis of power grid and scheduling automation and information technology that is crucial to the power system safety. Moreover, multi-agent techniques and IEC 61850 are employed to realize the fast communication between different agents, and manufacturing message specification (MMS) protocol plays a prominent role in real-time remote communication. Object oriented modeling approach is

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desired in the telecontrol system to achieve dedicated data communication network for dispatching automation [6]. Thomas has given the design of IEC 61850-based substation communication network (SCN) with real-time requirements for substation control and protection [7].

The rapid development of IP service swept not only the public communications networks, has also spread to power communication system. Based on statistical information of XiangJiaBa – Shanghai ±800 kV UHV DC transmission projects, the main voice communication of power application are gradually changing to the data centric communication with supporting optical fiber communication design. Data communication volume has exceed more than 80% of the total bandwidth requirements in the transport network nowadays [9], in which IP service is holding a dominant position, and service in electric power system is experiencing the same trend in many automatic controlling devices, i.e., automatic dispatching system, automatic data acquisition, etc. [10]. The bearer network of electric power system is constructed by heterogeneous technologies along with network evolution trend. For traditional WDM network, the traffic and wavelength are bound together in pairs, and optical channel transport unit are always customized with specified service flow. The optical transport hierarchy (OTH) is a new transport technology for the optical transport network (OTN) developed by ITU-T [11]. G.709 implements the optical channel by means of a framed signal with digital overhead that supports the management requirements for OCh. Furthermore, this allows the use of forward error correction (FEC) and the newly emerged network coding technology to enhance the system performance.

It is an economical cable laying method to used embedded fibers in aerial cable corridor, and there are two common approaches that already obtained widely application, i.e., all dielectric self supporting (ADSS) [12] and optical fiber composite overhead ground wire (OPGW) [13]. OPGW is usually used for the new constructed transmission line and the completed 200 kV (or above) high voltage transmission line to ensure the operational life and safety use. ADSS has the advantage of low investments and always use between regional substation or power line whose voltage is less than 220 kV. IEC 60870-5-104 upgrade IEC 60870-5-101 on the basis of using dedicated network scheduling communications protocol standard by replacing serial communication mechanisms.

Because the multi-agent system (MAS) techniques and real-time wide area communication are complicated and still in researching phase, it is a challenging work to develop the proposed hybrid switching network coding schemes in multi-agents and WAN Based Adaptive Protection System (MAWAPS) system. The electric power service model is experiencing evolution towards all-IP trends, i.e., WAMS [14], SCADA [15] and even the microgrid system [16]. Our previous researches prove that MAWAPS is feasible from the view of protective performance including the executing time in [10]. In the backbone transmission system, switch can be coupled with a wavelength selective switch (WSS) that is designed to direct any wavelength to any port, accept input wavelength channels from multiple directions, and can be able to drop two identical wavelengths from different directions through the same switch [17]. An embedded coding scheme in complex field is proposed to achieve a full diversity gain of relay transmission without any constraint of the control plane and management plane.

2. Hybrid switching network coding (HSNC) scheme

2.1. Brief introduction of power system communication architecture

The distributed integration function model is an important part of the auxiliary power system automation, standardization, and the model of the separation of the functional requirements of the system, through the reorganization of the hardware/software that implements the standard interface. The information models of the system usually need to take full account of the technology evolution roadmap in the next period of time to develop a long-term system planning. In the paper, we focus on the basis of the system control function of the overall electric power system [18], focusing on the large power grid interconnected data processing, network architecture of the intelligent layer/domain management, regional intelligent technology, respectively. Integration of distributed control function system is shown in Fig. 1, in which the HMI interface functions, device interface functions, data processing interface functions, network interface functions and management interface functions were launched.

This results in the introduction of two digital layer networks, the Optical channel Data Unit (ODU) and Optical channel Transport Unit (OTU). The intention is that all client signals would be mapped into the optical channel via ODU and OTU layer networks. It is suggested that a loose coupling between the traffic and working lamda, so that the physical line card can be easily reused and thus to protect existing investments [19]. Ahlswede first proposed the concept of network coding and theoretically proved that if the network information is processed by appropriate coding approach [20], multicast service can always achieve the theoretical maximum transmission capacity of the network. According to the polynomial algorithm with centralized encoding vector theory, we proposed a hybrid switching network coding schemes on the high speed backbone router of electric power system [21]. Consider first-in first-out (FIFO) operating system scheduling algorithm of each input port in packet level, head-of-line (HOL) packets contend for access to the switch output port [22]. If every packet is destined for a different output, the switch fabric allows each to pass though to its respective output. If k HOL packets are destined for the same output, one is allowed to pass through the switch, and the other $k-1$ must wait until the next time slice. While one packet is waiting its turn for access to an output, other packet may be queued behind it and blocked from possibly reaching idle outputs.

2.2. Hybrid switching fabric implementation

ROADM has the capabilities of dropping the lightpath that designated for local device and adding new lightpath, while optically switched paths will completely bypass the electrical cross-connect. The proposed HSNC module is designed with algebraic characterization of linear coding scheme, which is facilitated through the use of network coding on the preconfigured cycle for non-stop service in the power grid system. The deployed HSNC keeps continuous collecting information from different ongoing communication sessions from the electrical cross connect unit, and can process coded information in two different directions (transmitters and receivers) as in Fig. 2. Copies on two disjoint paths can be obtained from the electrical cross connector to take linear coding operations for the traffic carried at intermediated network nodes. High speed HSNC scheme only require an optical switching at the ingress and egress nodes: two transponder line cards are thus used for add/drop operations, one at the ingress and the other at the egress OXC of any lightpath [23]. With HSNC, an optical path can cross various transparent optical network elements with reconfigurable optical add/drop multiplexer. The number of transparent optical network elements that can be crossed by an optical path before 3R regeneration, and packet cross-connect (PXC) that introduces significant optical impairments (e.g. attenuation, dispersion) shall be therefore strongly limited. Each ROADM that embeds HSNC module will execute the above coding procedure, and the effective bandwidth of each device in a network depends on many factors including the offered load, traffic pattern, available bandwidth and data rate, priority mechanism, etc. HSNC module will record