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Applications of forecasting based dynamic p-cycle reconfiguration under reliable optical network in smart grid

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ABSTRACT

There is a significant motivation to increase restoration speed of electric power communication network by using mesh-based schemes, because they can always take less time to achieve network convergence. However, on the other side, it often involves large amount of extra overhead and thus consumes more controlling bandwidth. In order to design efficient survivable transport network, we propose a forecasting based p-cycle (FDP) to adapt to the rapid development of information communication technology network and the communication infrastructure of further smart grid. The proposed approach has the immediate benefit of providing natural reconfiguration under dynamic service requirement by investigating the statistical properties of power grid. Interface of GMPLS control plane and been extended for the proposed approach, and several reconfiguration approach is evaluated with the support of distributed pre-configuration scheme using GMPLS and new LSA type in OSPF-TE to realize this scheme. We also analyze the performance of decentralized control algorithm over information networks whose topology matches that of underlying power network and use analytical approach to determine whether the proposed method works well under different reconfiguration strategies. Additionally, various classical p-cycles enumeration algorithms together with distributed configuration protocol from previous work are evaluated under FDP approach and the efficiency protection resource utilization is examined.

1. Introduction

The concepts of smart grids increase the connectivity, automation and coordination between power suppliers, consumers and networks that perform either long distance transmission or local distribution tasks. In recent years many intelligent electronic devices, are undergoing an increasing deployment in private homes in order to fulfill the global energy saving goal. Smart metering, as a newly emerged technology, are certainly deserved a great deal of attentions in the next generation power system [1–3]. There are many aspects that need to be seriously considered, i.e., transport media, communication protocol, network architecture, security and interoperability [4]. Robust two-way communications, advanced sensors, and distributed computing technology are expected to improve the efficiency, reliability, and safety of power delivery [5].

Previous research has proved that thousands to millions of pieces of field equipment on-line in modern power system are experiencing an upward trend on technical integration across power engineering domains as well as information systems and embedded computing devices. IEC TC13 are focused on standard for electricity metering, and have constituted IEC 62056 series of standard on the data exchange for meter reading, tariff and load control aspects. The standard group has not reached an agreement on lower layer communication technology and the way data concentrator works yet, and there are always different working approaches for electricity metering: some use the DLMS/COSEM [6] with narrow band power line communications (PLC) [7] or RS-485 while others prefer wide band wireless or optical fiber communication technologies [8]. PLC is also known as power line carrier, it cannot be widely used for the substation with bi-voltage transformer (two different voltage levels on the output are used at the same time), as there is always only one data concentrator that could be connected on the secondary of the transformer [7]. Besides, there are great challenges for PLC due to electromagnetic compatibility (EMC) interference and routing problem. Effective interference-avoiding algorithm is desired to meet the requirement of software radio, which should work together with an adaptive detection scheme depending on receiving signal. As with the continual improvement of main network structure of electric

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power system, most of the regional grid has been working on hierarchical mode, and the electromagnetic loop network has also been restrained to improve the transmission ability. Optical ground wire (OPGW) that combines the functions of grounding and communications is always used during the construction of electric power transmission and distribution lines. It contains a tubular structure with one or more optical fibers, surrounded by layers of steel and aluminum wire. Typically OPGW cables contain single-mode optical fibers with low transmission loss, allow long distance transmission with ultra high speeds. There are not always high bandwidth two-way communication channels between smart meters on customer side and the remote controlling platform, most of the collected data are aggregated though the concentrator, and then encapsulated into fiber channel. The growing trend of IP technology and large amount of data volume increases the risk of network failure and high efficient survivability is required for further smart grid applications.

In telecommunications network, 1 + 1 path protection, span restoration with spare capacity assignment (SCA), joint capacity assignment (JCA), and shared backup path protection (SBPP) are the most widely applied mesh survivability schemes. Meanwhile, the pre-configured cycles (p-cycles) have been widely investigated in recent years as a newly emerged network protection technique. Similarly, the p-cycles are fully pre-configured with preplanned spare capacity and when a span failure occurs, only the two end nodes on failed span take real-time switching while without any switching actions required for intermediate nodes on cycles (Fig. 1(a)). P-cycles cannot only provide fast protection against on-cycle span failures, but also the straddling span failures and node failures, and they have higher resource efficiency due to protection resource that shared by several potential failures [9]. The p-cycle protection mechanism aims to provide ring-like restoration speed while retaining the desirable capacity efficiency of the mesh-restorable alternative [10,11]. In previous works, to achieve the theoretical efficiency limit of mesh networks, extensive works have been done with Hamiltonian p-cycles [12–14]. Network survivability with node- or multi-spans-failure has been studied with measurable mathematic model [15]. Fig. 1(b) presents an

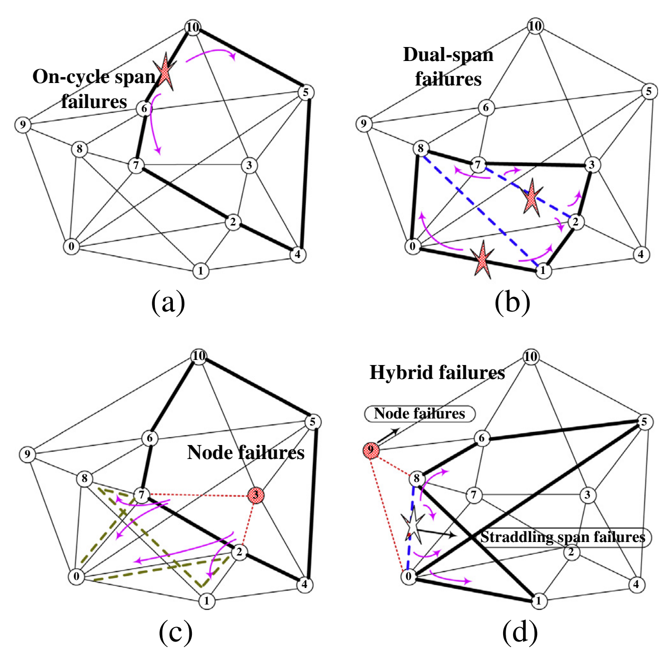

Fig. 1. Illustration of p-cycle protections. (a) On-cycle span protection, (b) dual-span protection, (c) node protection, and (d) hybrid protection (node failure and straddling span failure).

illustrative demonstration of p-cycle protection for dual link failures, it can be fully restored for almost triple amount of spare capacity. As depicted in Fig. 1(c), node failure (node 3) can be protected by node-encircling p-cycle (NEPCs) [16] (2–4–5–10–6–7–2) or the flow p-cycle [17–19] (1–2–0–7–8–1). Also the hybrid failure model is investigated to simplify configuration and further reduce the resource redundancy, for example, the extended p-cycle (0–1–8–6–5–0) (Fig. 1(d)) can protect either straddling span failure (8–0) or node failure (9). To the best of our knowledge, segment-path-protecting (SPP) p-cycle was first proposed to provide transiting flow restorability with reduced operational complexity [16,19,20]. Furthermore, joint optimization of working paths and spare capacity with an operational simplicity close to that of span restoration is formulated and reported [21,22] which is preferred in multi-region and multi-layer networks (MRN/MLN) design.

As proved by previous works [19], the p-cycle based network can be 3–6 times capacity-efficient than traditional ring-based networks while still providing BLSR ring switching speed and simplicity. This attractable property greatly motivate p-cycle applications on IP/MPLS layer [17], WDM network [23], and even cross-layer recovering [24].

In this paper, a forecasting base dynamic p-cycle (FDP) reconfiguration model is proposed that adapt to the rapid change for the traffic volume from different stations, the protection capacity can be efficiently configured according to the most recent predictive value. Protection schemes that applied to electric power communication network is still quite simple (i.e., traditional 1 + 1/1:1, M:N approach), which is somewhat inadequate for the newly involved service for the security I–IV section especially for the increasing demand from the Integrated Data Network (IDN) of the State Grid Corporation (which is the largest state-owned electric utilities company in China). To the best of our knowledge, there have not been any literatures that indicating the p-cycle applications in China or practical use in any power communication network all over the world by using forecasting traffic flow, even though there are lots of research for these new survivability technologies. The motivation in this paper is mainly to provide a high-reliable solution for new type of data service in current and future smart grids, e.g., WAMS, power dispatching, energy efficiency acquisition. In Section 2, we present a novel architecture for next generation intelligent devices (NG-IEDs) according to the recent smart gird user interface specification IEC PC118. To support the application of FDP in MRN/MLN, the interface extensions of GMPLS control plane are described and experimental results are presented to evaluate this approach under different reconfiguration mode in Section 3. Simulation results by the ASON simulator which is also implemented on our previous work in [25] show that the proposed approach can efficiently help the engineer to overcome utility infrastructure challenges under advanced meter infrastructure (AMI) applications. Finally, some discussions are presented in the last as the conclusion to this paper.

2. FDP reconfigurations in next generation smart grid

2.1. Novel architecture for NG-IEDs

Traditional operating information in power system is collected by artificial approach periodically, and it's certainly a heavy and error-prone task. For example, smart meters collect real-time data which can be obtained from large amount of IEDs, and then store the collected data regarding electric power consumption of different devices for future historical analysis purpose [6]. A generalized IED is not only responsible for traditional function in power system, (i.e., CT/VT sampling, I/O data exchange, monitoring and supervision), but also the time synchronization and advanced