Performance Evaluation of Smart Grid Communication Network Using MPLS

S. PremKumar and V. Saminadan

Abstract — **The power grid integrates multiprotocol label switching (MPLS) technologies into existing backbone communication networks present between substations and control centers. MPLS is an emerging technology for smart grid communication networks. MPLS uses labels to identify the packets. This paper proposes path protection using MPLS traffic engineering for IEEE 30 bus system communication network for smart grid. Resiliency is achieved by means of end-to-end restoration capabilities that enable the network to reroute the path around a failure. The proposed approach is validated using OPNET.**

***Index Terms*—Multi Protocol Label Switching, Internet Protocol, Traffic Engineering, Smart Grid**

I. INTRODUCTION

The present electric grid which was established in the beginning of 19th century is one of the multiform system created at all times. This system contains transmission cable, circuit breakers, feeders, fuse etc mounted together in an integrated manner with communication enabled. During the later part of nineteenth century the power grid system puts computer and sensors to monitor and control the grid. In the past decade these sensors are replaced with intelligent electronic devices designed exclusively for effective monitoring and control of the power grid. Hence, smart grid was introduced with aim of overcoming the weakness of conventional electric grid by using smart grid based intelligent electronic devices.

The smart grid model improves quick and real time monitoring with advanced control of the power system equipment present at far of locations thereby improving system reliability and quality of service. However it seems these are all not possible without considering the key role of communication technology. Existing power system network infrastructure does not have continuous and centralized monitoring of power system devices which are present at various substations. The present data available has more delay and hence it is not possible to provide real time situational awareness of the power grid network [1].

Multi-Protocol Label Switching based data communication network provides minimum latency for the data that are to be processed at the control center for real time monitoring of the grid. The data scanning rate, refreshment rate of the supervisory control and data acquisition (SCADA) system of a power network is not prompt enough to provide adequate information about the state of a power network in real-time and dynamic manner. The latency required for the continuous monitoring of the power system data is less than 20msec. Baki [2] suggested a continuous monitoring of smart grid devices through MPLS network with minimum delay. Kansal et al [3] developed a model to determine the parameters to simulate a communications system for a power grid starting from the power network configuration and measurement of data. Lin et al [4] proposes a power/network co-simulation which integrates power system dynamic simulator and network simulator together using synchronization mechanism. However, the resulting throughput, packet loss rate and round trip time is comparable to that of an open flow network where flows do not expire or MPLS low bandwidth network with similar traffic demands [5].

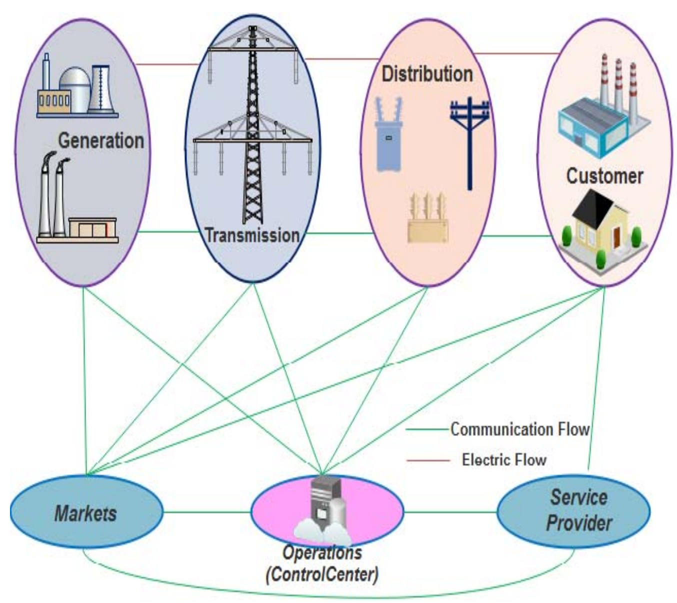

Fig. 1. Smart Grid Network

Based on the theoretical study it was concluded that MPLS has considerable advantages over traditional IP networks. In this work MPLS with traffic engineering is proposed to reduce

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delay and avoid congestion. This paper is organized as follows: Section II points out the optimal placement of phasor measurement units (PMUs) and the backbone data communication network requirements for wide area monitoring using MPLS technology. Section III presents the proposed communication network model based on the MPLS standard which can be used for the smart grid applications. The MPLS based smart grid communication network is modeled in opnet and the performance parameters are analyzed in Section IV. Finally, the paper is concluded in Section V.

II. SMART GRID MODELING REQUIREMENTS

A. Numerical Observation Analysis (NOA)

A power system needs complete observation of the network state estimation to have complete observability. Hence, the power system observability can be performed using NOA by placing PMU's in all the buses and sequentially eliminating from different buses one by one and stopped when the measurement sets obtained from the remaining PMU's can make the system completely observable.

B.PMU Placement problem formulation

The optimal PMU placement for an N bus system is formulated as follows

$$Min\sum_{i=1}^{N} c_i p_i$$

S.t $F(C) \geq b$

where, c is the binary decision variable vector for PMU placement, whose entries are defined as

$$p_i = \begin{cases} 1 \; if\ PMU\ is\ placed\ at\ i^{th}\ bus \\ 0 \qquad\qquad\qquad otherwise \end{cases}$$

b is an unit vector of length N, i.e b=[1 1 1…]^T.

c_i is the cost of PMU installed at ith bus.

F(*C*) is the observability constraint vector function, whose entries are non-zero otherwise. If the corresponding individual buses are observable with respect to a given measurement set and zero otherwise [6].

C. Multi Protocol Label Switching (MPLS)

A smart grid running on a converged communications network architecture utilizing internet protocol (IP) and multi-protocol label switching (MPLS) can support all services. The MPLS provides higher speed, bandwidth, reliability and repair potentials to meet the growing data and two-way communications needs of today's smart grid power distribution systems. IP network cannot determine a route that a specific data packet will take when it is sent across the network. It also cannot determine the amount of time it will take to get to its destination. IP network is not sufficient for utilities that require mission-critical operations of traffic. However, IP over an MPLS network can solve the problems.

MPLS is an efficient packet forwarding mechanism with potentialities of data link layer and network layer. It transports data from nodes present in one network to another network by using labels instead of IP based addressing. MPLS uses labels to identify the path of packets that should traverse through the network. Some of the protocols that are used in MPLS are open short path first protocol (OSPF), Resource reservation protocol (RSVP) and border gateway protocol (BGP). It combines the advantages of IP routing and simplicity of label switching. MPLS is not a alternate for the IP based data communication but it is an expansion for IP architecture by including dynamic functionalities and applications. The primary functionality of the MPLS is attaching short fixed-labels to the packets that enter into MPLS domain. The typical Components of of MPLS network are customer edge (CE), label edge router (LER) and label switching router (LER). The CE puts the data into IP packets and sends to the ingress LER. The LSR acts as a transit switch in the MPLS backbone network. The labeled IP packets are received through the appropriate LSPs and finally sent to the egress LER. MPLS label is a short fixed entity with no special structure. Label is placed between layer2 (Data Link Layer) and layer3 (Network Layer) of the packet to form Layer 2.5 label switched network on layer 2 switching functionality without layer 3 IP routing. MPLS is an evolving technology for high performance packet control and forwarding mechanism for routing the packets in the data networks. MPLS has developed into a salient technology for efficiently operating and managing IP networks because of its efficient functionalities in providing traffic engineering (TE) [7].

D. Traffic Engineering (TE)

Traffic Engineering (TE) is a mechanism by which the communication resources can be controlled (such as automatic bandwidth adjustments for traffic engineering tunnel relative to the need) within the networks without affecting the quality of service. The key features of TE are resource reservation and optimal resource utilization. To balance the load on different links, routers, and switches in the network are enabled with TE by providing an alternate path in case of link failure or congestion. The key function of Traffic Engineering is to create economical and reliable IP network operations without compromising the network performance. MPLS networks use TE mechanisms to reduce network congestion and reroute the traffic if any node or link fails in the network and additionally improve the network performance. TE modifies routing patterns to provide efficient mapping over traffic flows to network resources. The efficient mapping will scale the incidence of congestion and play an important role within the implementation of network services with secure quality of services (QoS) [8].

III. PROPOSED SMART GRID COMMUNICATION NETWORK MODEL

For the analysis of different communication architecture in real -time various tools such as NS2,GNS3,OMNET++,OPNET etc are available in the markets nowadays. The proposed communication network for the IEEE 30 bus system is modeled and analyzed using OPNET.

A.MPLS Smart Grid Scenario

The IEEE 30 bus systems' communication network consist of 30 nodes(routers) that are internetworked to each other by SONET OC3 cable, of these 30 nodes 7 nodes are placed in the substations. The substations which are equipped with PMUs are 2,3,10,12,18,24 and 30 in the IEEE 30 bus system. Fig. 2 shows optimal placement of PMUs in the IEEE 30bus system. The 7 routers which are placed in the optimal position of the IEEE 30 bus system will be considered as a subnet. Each of these nodes is considered as a sub network. Configuration of dynamic LSP between LER_1, LSR1, LSR2, LER_2 using the MPLS_E-LSP_DYNAMIC link, Create a bidirectional route from LER_1 to LER__2. LER1 is the substation edge router and LER2 is the control center edge router, LER1 is connected to regional substation1 LSR, using SONET OC3 link. Similarly LER2 is connected to regional substation2 LSR, using SONET OC3 link. And then connect the LER1 to LER2, using DYNAMIC LSP. Similarly Configure a DYNAMIC LSP between LER_2, LSR2, LSR1, and LER_1, create LSP path same as above but from LER_2 towards LER_1 on the top path. All the data from the PDCs will be collected by the super phasor data concentrator (SPDC) which is connected to the core edge router of the control center.

B. Substation Scenario

The smart grid communication architecture consists of six substation. Each of the substations are equipped with various teleprotection devices, PMUs and IEDs that are connected to the substation router by using 100 Base-T links. Fig.3 shows that the network simulation model of proposed substation scenario. We have assumed the core edge routers are placed in the substations equipped with phasor measurement unit. These data collected from these PMUs are transmitted through the backbone communication network to the phasor data concentrator and finally to the control center.

The proposed MPLS based communication network provides low latency end to end delays to have efficient monitoring of the power network. MPLS-TE tunnels provide alternate paths in case of link failures in the communication network. The networks without tunnel have more delays compared to networks with tunnels. By providing efficient communication network topology the real time data required for stable monitoring will be useful to enhance the operation of the grid. The control center (CC) for this power system network will be chosen such all the distance between the CC and PMU located substations are minimum.

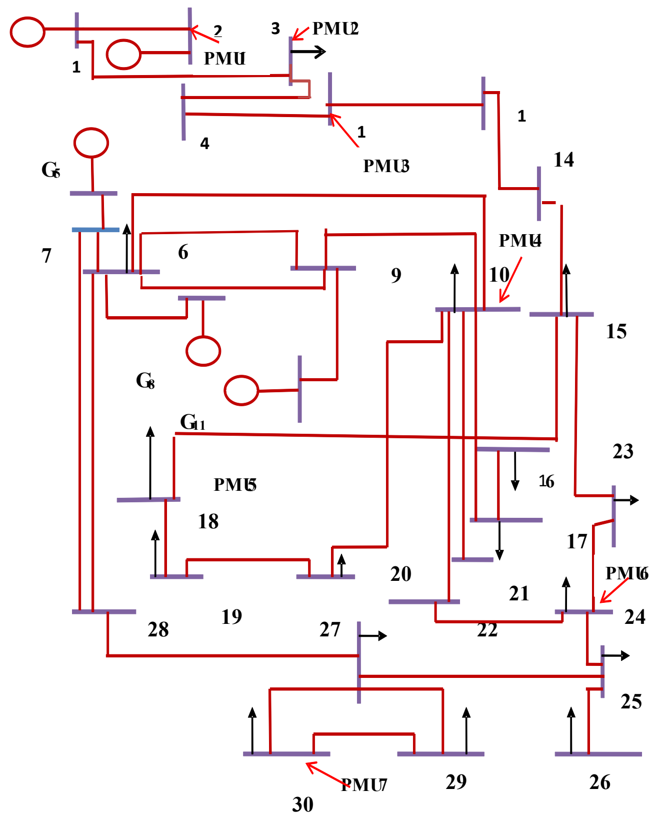

Fig. 2 Optimal PMU placement of IEEE 30 bus system

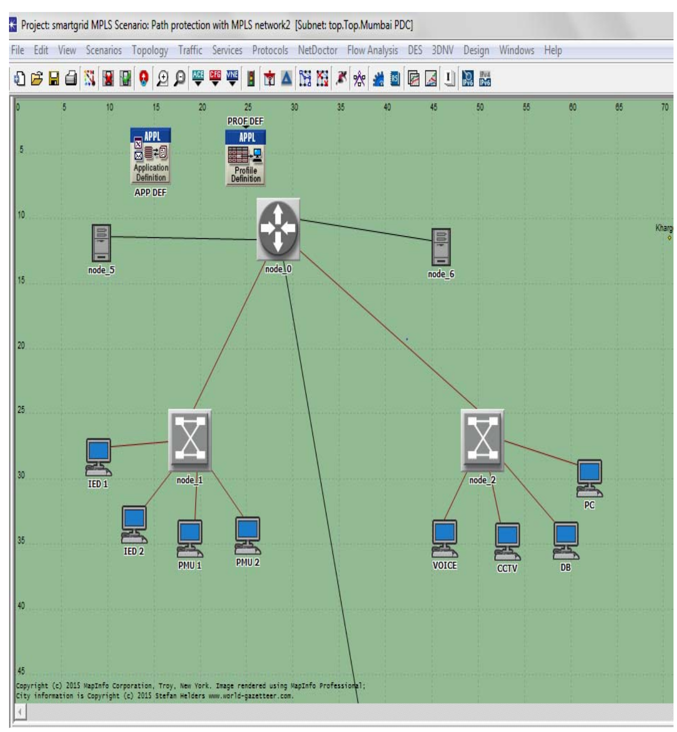

Fig. 3 Substation Scenario

IV. SIMULATION RESULTS

Implementing MPLS with TE minimizes the congestion in the network and provides the better utilizations of network links. MPLS suffers minimum delay and provides high throughput. It is understood that the timeframe in which the links are made to fail shows there is heavy loss of traffic in the case where there is no MPLS-TE Technique used in the network. Where there is an implementation of MPLS-TE Mechanism using N Hop there is great increase in the performance of the network and the performance metric in the study is the traffic received. The comparison graph of Path Protection in the network is shown below. The graph shows the comparison of the network performance in the case of node or link failure in the network with MPLS-TE and without MPLS-TE.

Fig 4 shows that LSP delay of primary path and Fig. 5 shows that the LSP traffic sent and traffic received of primary path. Fig.6 shows that LSP delay of backup path which is maximum delay when compared to primary path of LSP delay, and Fig 7 shows that the traffic sent and traffic received for backup LSP. The traffic received from LSP is deceased. Here there is heavy loss of traffic where there is no MPLS traffic engineering technique is used in the network. The network has same traffic sent and traffic received in the LSP router due to MPLS-TE which is shown in Fig.8 and Fig.9 shows that the LSP traffic reroute time. Fig.10 shows that the LSP delay of backup path with MPLS-TE which has minimum delay when reroute the traffic. When there is any failure on the network the LSP reroute the traffic with minimum time.

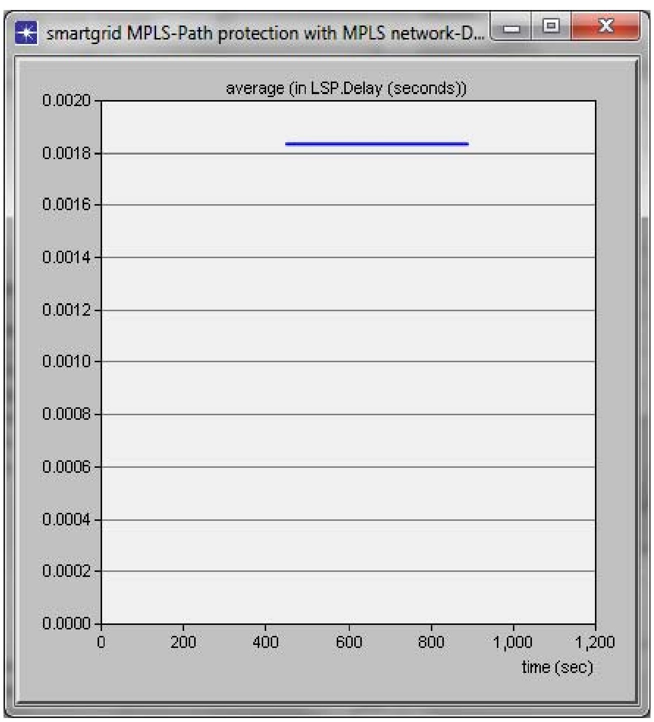

Fig. 4 Primary LSP delay

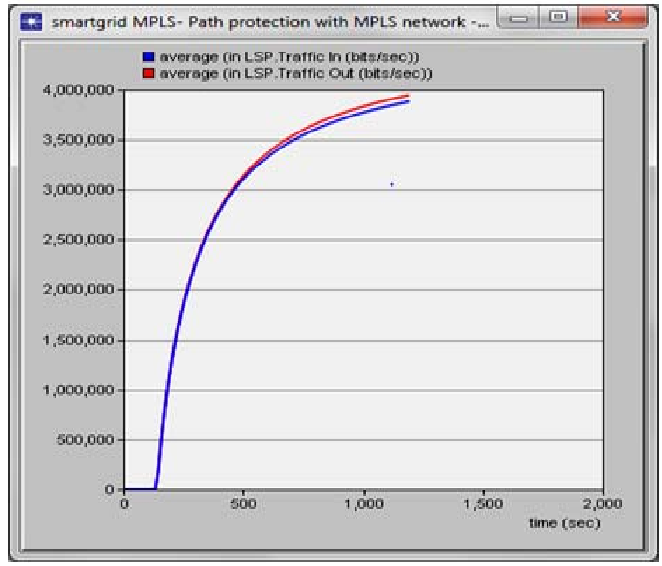

Fig. 5 Primary LSP traffic sent and received

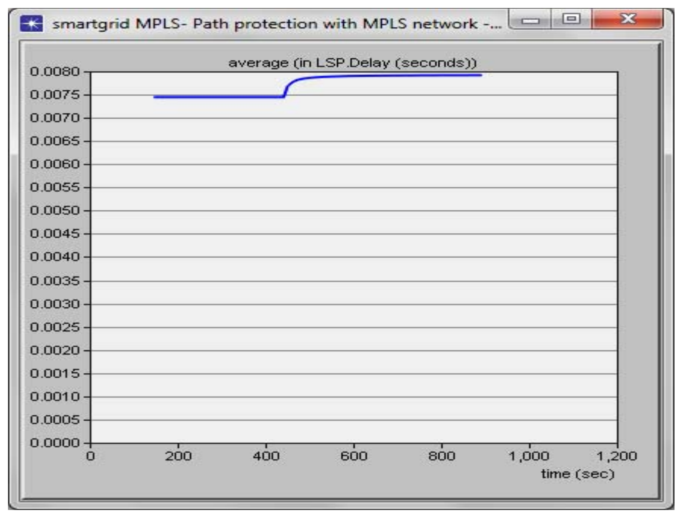

Fig. 6 Backup LSP delay without TE

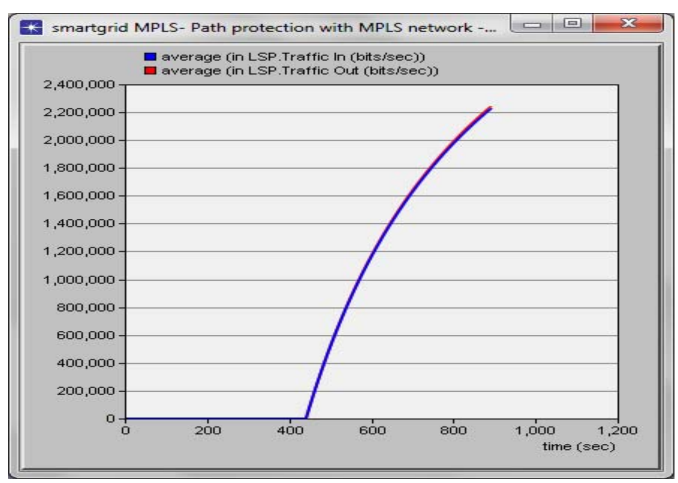

Fig. 7 Backup LSP traffic sent and received without TE

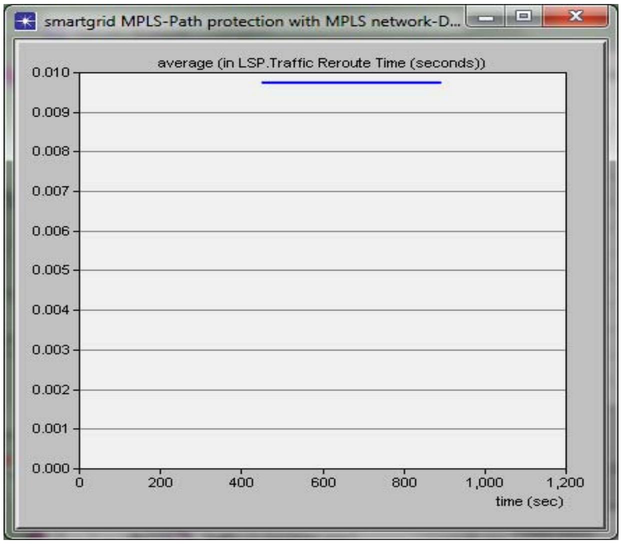

Fig. 8 Backup LSP Reroute time with TE

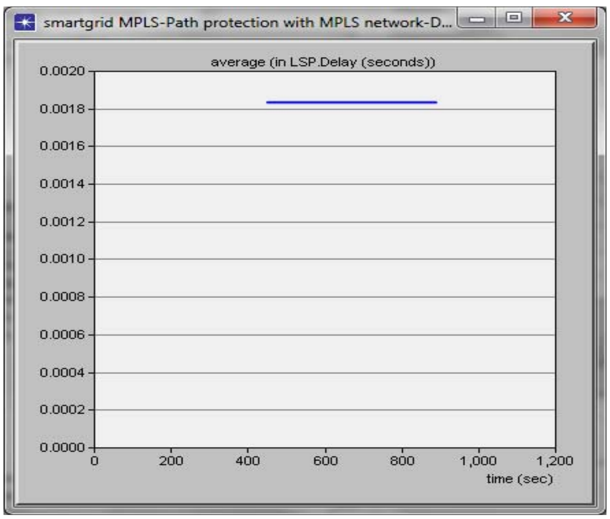

Fig. 9 Backup LSP Delay with TE

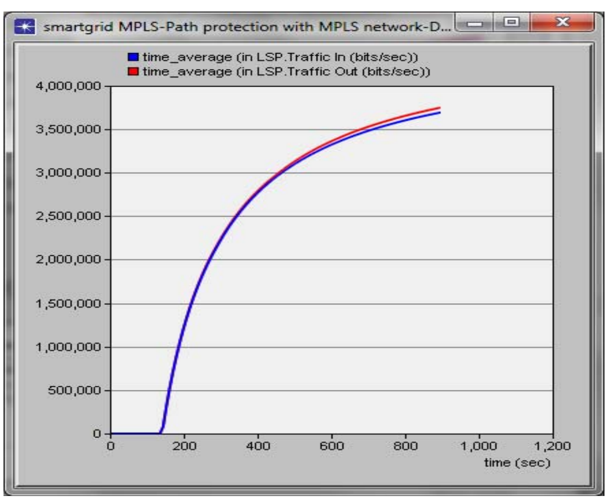

Fig. 10 Backup LSP traffic sent and received with TE

V. CONCLUSION

In this paper the performance of IEEE 30 bus systems' communication network using MPLS technology were analyzed. The result obtained shows that the use of MPLS architecture in SG communication offers a range of additional benefits and improvement. Path protection using MPLS-TE in Smart Grid is proposed. The link failures in the communication path can be recovered by means of path protection using MPLS-TE. The fault notification sent by the corresponding router before the failed link is responsible for rerouting the traffic and sends the packets which are unable to reach the destination. Any failure at any point along the path of a circuit will cause the end nodes to move the traffic from a new route. A backup LSP is established, in advance to provide failure protection for the protected LSPs that is carrying network traffic. Hence the simulation results show an appropriate end to end delay, traffic sent and received and the reroute time of network traffics in failure situations. The simulation proves that the delay is reduced and has very minimum time when reroute the traffic using MPLS traffic engineering.

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