The Journal of CPRI,
Vol. 13, No. 4, December 2017 pp. 525-532

IEC 61850 Client Redundancy for Substation Automation System

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This paper presents an overview of System level redundancy implementation in an IEC61850 based Client application and method used to reduce recovery time after failure of the station level application (IEC 61850 Client, HMI and Database). The authors have presented the implementation of a dual Server hot-standby redundancy architecture, Network Driver (NDIS-Network Driver Interface Specification) for heartbeat communication, network teaming for redundant network redundancy and database replication for substation data integrity and availability of substation data/event. This paper also discusses different redundancy modules (Redundancy Manager, IEC 61850 Client Driver, HMI, Database Module) integration like API integration between Network driver (NDIS) and IEC 61850 Client application. The implementation of data queue in IEC 61850 Client to avoid data loss during server switch over is discussed in this paper. The authors have presented the various fail-over mechanisms in this system. As the redundancy has a direct impact on the cost and complexity of the system, the proposed solution in this paper has addressed the needs of application criticality and customer requirements.

Keywords : *System level Redundancy, Communications Network Redundancy, Substation Automation System (SAS), HMI, NIC Teaming and IEC 61850.*

1.0 INTRODUCTION:

The Substation Automation System (SAS) is evolved over a period of time and has now become an integral part of utilities, performing the important task of managing the resources optimally to provide uninterrupted and quality services to consumers. The introduction of IEC 61850 based compliant systems in substation automation system has resulted in increased data availability, data processing power in IED (Intelligent Electronics Device), interoperability, higher reliability and easy user configurability.

Redundancy in general, is a provision kept in the form of standby equipment to improve reliability, stability and availability of any system. There are various mechanisms through which redundancy is achieved in a substation automation system. Redundancy can be applied at multiple levels i.e. at System level, at device level or at both levels. The system level redundancy can be achieved by using various protocols and Technologies like RSTP (Rapid Spanning Tree Topology), MRP (Media Redundancy Protocol), Load Sharing, Network Driver (NDIS) communication, NIC Teaming, and Database Replication. The device level redundancy can be achieved by using duplicating hardware and with an intelligent monitoring of those duplicate hardware.

In a Substation Automation System the redundant network and the redundant IEC61850 Clients play critical role in acquiring un-interrupted data from IEC61850 Servers. At present the challenge faced by substation automation vendors is the

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implementation of IEC 61850 within a redundancy context, both at the bay level (Device Level) and station levels (IEC61850 Client, Database, HMI), and its effect on the overall response time of the substation system.

Substation automation chiefly consists of three levels.

1. Station level-

IEC 61850 client with operator console, which gathers information from various IEC 61850 Servers (IED devices) and enables local control and supervision at station level.

2. Bay level- IED.
3. Process Level – Instrument, transformers and Breakers etc.

Station level redundancy implementation in a substation automation system is discussed in this paper.

Redundant/Standby IEC61850 Clients in an IEC 61850 communications face the challenge of ensuring the field device data availability in the central database server and also ensure that there are no events or data loss during switchover from primary to secondary IEC 61850 client. Network and Application redundancy is required for substation automation system in order to guarantee that the network is resilient to both communication failures and application failure.

Some of the SAS vendor provide a redundant client with independent database and HMI i.e. two separate server loaded with IEC61850 Client, run concurrently with each server having its own Database server and HMI screen. This solution serves well in situation where the number of operators is limited to two. The data in database servers and the HMI screens is not in sync and fails when the number of operators is more than two.

The proposed solution provides hot-standby IEC 61850 Client Redundancy for all sections of substation automation system. This solution has a dual server architecture and the same can be extended to N+1 server redundancy with minimal configuration modification. In this architecture it is proposed to offer/have NIC teaming for dual Ethernet redundancy and database replication for data synchronisation between the database server and NDIS driver for heartbeat communication.

2.0 LITERATURE SURVEY :

The following papers are studied

2.1. Redundancy challenges of the IEC 61850 systems by Carlos Rodriguez, Javier Figuera, Daniel Prieto, Rodolfo Pereda and Aitz Amezaga.[1]

This paper is mainly focused on communication and network redundancy options on IEC 61850 system. This paper discussed on Ring network topologies and Rapid Spanning Tree Protocol (RPST) and its configuration, drawback of this topology when a Goose applications requirement is there. So the author proposes a new protocol i.e. Parallel Redundancy Protocol (PRP) or High availability Seamless Redundancy (HRP) and the hybrid of this two protocol. But this paper is not discussed more on dual network redundancy and its application on a redundant IEC 61850 system.

2.2 Network redundancy in substation applications by Clemens Hoga.[3]

This paper discussed on various possibilities for Ethernet media redundancy in real Substation layouts i.e. Real Ring, RSTP (Rapid spanning Tree Protocol), PRP (Parallel Redundancy Protocol), HSR (High availability of seamless ring) and hybrid of PRP – HSR. This paper also discussed the advantage disadvantage and application of these protocols In IEC 61850 substation automation.

3.0 SYSTEM DESCRIPTION AND IMPLEMENTATION:

The proposed system consists of three modules Redundancy Manager Service (RM), IEC 61850 Client Driver and Database.

The system provides Dual Server hot-standby Redundancy architecture (two servers i.e. a primary server and a secondary server). The system architecture is as shown in Figure 1.

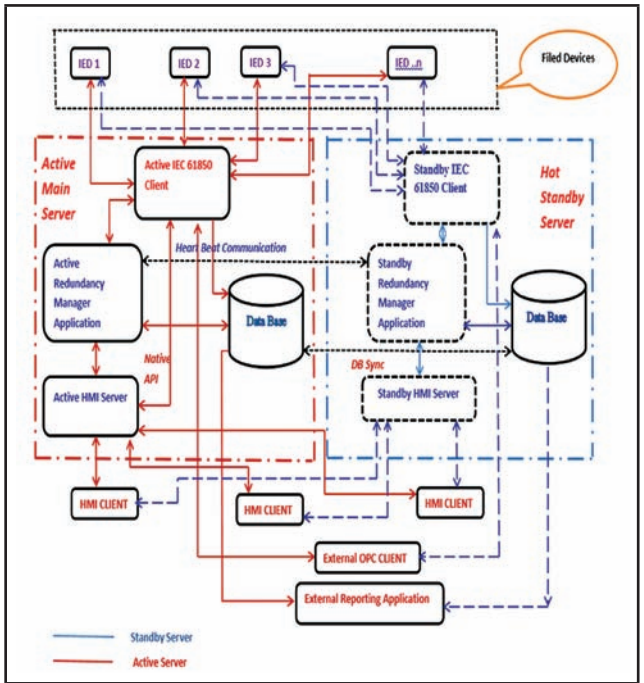

FIG. 1: ARCHITECTURE OF REDUNDANCY IMPLEMENTATION IN IEC61850 CLIENT

3.1 Redundancy Manager Service (RM):

The redundancy manager service detects a fail-over condition (the fail-over condition may occur due to application failure, network failure and power failure or due to a System shutdown). The redundancy manager is installed in both primary and secondary servers. Redundancy managers have their own communication channel to interact between themselves once in 1m sec. When a fail-over condition is detected by redundancy manager, it initiates a command for the Standby Server to take over the control from the primary server. The control comes back to primary server only when all the conditions i.e. network communication, application status and database status are good. The redundancy manager module can communicate with 16 numbers local or remote applications for monitoring and control without any degradation in performance. Redundancy manager Communication with IEC 61850 Driver application is shown in Figure 2.

```
Installing Sample NDIS Protocol Driver...
INF Path: D:\Final Code for RM\RM Code\CODE\RManager\NDISPROT.inf
PnpID: MS_NDISPROT
The requested service has already been started.

More help is available by typing NET HELPMSG 2182.

Successfully getting the mac-address and device-id.
1HANDLE =f1c for dev \\.\NdisProt
Opened device \DEVICE\{BEA4B685-2094-4CD2-ABC6-DF6B96F47DB6} successfully!
This is primary server.
 All CA not running
Now Control conning to Primary
In constructor
CA control server now start send/recv.
1 All CA running
Accepted incoming connection
send update
send update
```

FIG. 2: REDUNDANCY MANAGER APPLICATION

On primary server heartbeat communication between primary server redundancy manager and secondary server redundancy manager is shown in Figure 3. The initial response time is high due to activation of all services in redundancy manager application.

```
More help is available by typing NET HELPMSG 2182.

Successfully getting the mac-address and device-id.
1HANDLE =f48 for dev \\.\NdisProt
Opened device \DEVICE\{129200FF-4174-48AC-A206-4868E5B963F6} successfully
This is secondary server.
Response Time In Micro = 483883
Response Time In Micro = 218
Response Time In Micro = 248
Response Time In Micro = 254
Response Time In Micro = 176
Response Time In Micro = 188
Response Time In Micro = 177
Response Time In Micro = 171
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FIG. 3: HEARTBEAT COMMUNICATION TIMING

3.2 System Configuration for Redundancy Manager:

Microsoft Windows Server/Win XP/Win 7 and MySQL 5.2 are installed on both the servers. One of the servers is configured as primary server and the other server is configured as secondary server. Both the servers have their own internal storage and no shared storage is used by them.

The Figure 4 depicts the physical network connections in the system. Both servers are directly connected to each other via a cross-over Ethernet cable to monitor heartbeat communication. Each server is connected to the public network two redundant Network Interface Card (NICs).

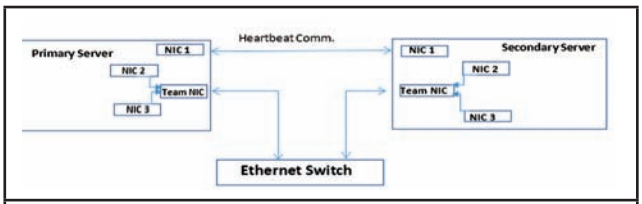

FIG. 4: RM NETWORK

The dedicated cross-over Ethernet connection for heartbeat communication plays the critical role of updating the server status to the peer server. It also informs the secondary server about failure of any resource at the primary server. The resource may be an application- running in the server, Database or network service or failure of the devices connected to the server. The other two NICs in the server are responsible for the communication between other applications/ servers in the Local Network (LAN).The failure of any one of the NICs in server will not affect the operation as the Team NIC is active. The team NIC will be active as long as any one of the NICs in the server is available. The team NIC will fail when all the NICs in that particular server fails. The maximum number of NICs supported by redundancy manager in this scheme is four, 1 for Heartbeat communication and the other 3 NICs for LAN communication. Only single instance of the RM application/service is allowed to run in the server.

3.3 Functioning of Redundancy Manager (RM):

RM checks the status of the running applications like IEC 61580 Client Driver and HMI. The primary Server side RM updates their statuses to the secondary Server side RM.

The Figure 5 below shows the communication between client, Redundancy Manager and the Database.

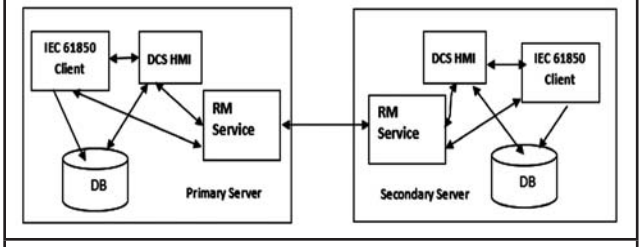

FIG. 5: CLIENT AND RM COMMUNICATION

3.4 Fail-over Management in Redundancy Manager:

NDIS 5.2 library is used for the development of a highly reliable communication driver. The function of this driver is to establish communication between two redundancy mangers installed in the primary and secondary servers. This communication channel is popularly known as heart beat communication. When a failure is detected by NDIS driver, it informs the RM and which takes necessary steps to fail-over to the secondary node and re-route the client traffic.

The different cases for server switchover is used in this configuration is given below.

- Both servers power on then primary server will be in active mode and secondary server will be standby mode.
- When primary server fails then secondary server will go to active mode.
- Primary server restored, primary server will come to active mode and secondary server will go to standby mode.
- Primary server is not in the network i.e. power failure or disk failure then secondary server will go to active mode.

Case for application failure and switch over condition is illustrated below and redundancy manager communication between primary and secondary server is given in Figure 6.

- Kill the IEC 61850 Client Driver application on primary machine i.e. application failure checking.

Result: The redundancy manager service of the secondary server got the control and its signals IEC 61850 Client Driver application of secondary machine to start updating data in to data base and data in DCS system.

- Restart the IEC 61850 Client Driver application on primary machine i.e. Switchover from secondary server to primary.

Result: When the IEC 61850 Client Driver application on primary machine restarted, the redundancy manager on secondary machine got the notification from primary machine redundancy manager. The redundancy manager of secondary machine instruct it local IEC 61850 Client Driver application not update data in database and same

time in DCS system. And same time IEC 61850 Client Driver application on primary machine got notification to update data into database and DCS system.

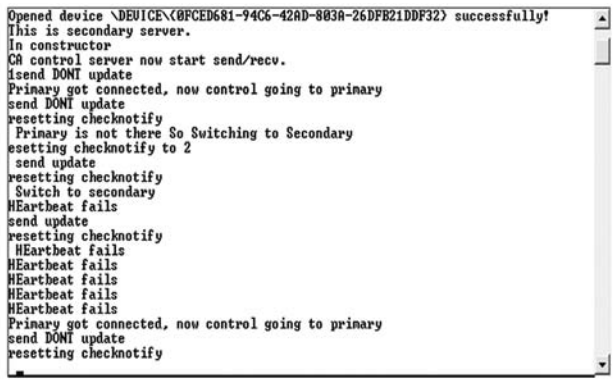

FIG. 6: FAILOVER FROM PRIMARY TO SECONDARY AND VICE VERSA

3.5 NIC Teaming for Dual Network Redundancy in Substation Automation System:

NIC Teaming /NIC bonding is the process of operating multiple NICs as a single NIC interface. It is a solution popularly used to ensure network availability and to improve network performance. In this context NIC teaming is implemented using Broadcom NIC card and Window XP OS. This concept is not limited to Broadcom NIC card and Window XP OS.

In order to implement NIC teaming in this scheme, multiple NICs are bonded to single logical team NIC (in Figure 4), in both the servers, and is produced a unique IP address. All communication from the servers in the network takes place using the Teamed NIC. When any one of the NICs in a teamed NIC fails the communication to that system doesn't break as the Team NIC channelizes the communication using the other available physical NIC. This provides a dual Server level network redundancy for Substation Automation System.

3.6 IEC 61850 Client Driver:

This section of paper discusses on the redundancy and client architecture in an IEC 61850 clients at station level. The IEC61850 Client driver is based on SISCO libraries and MMS stack. The IEC 61850 Client driver module provides a higher level Application Programming Interface (API) for integrating with Redundancy Service Module and Database Module. IEC 61850 Client Driver provides a Communication service to both OPC Client and DCS System.

IEC 61850 Client Reporting and Logging services require additional redundancy at Client Level. To achieve redundancy in IEC 61850 Client at station level, the configuration in both IEC 61850 Client runs concurrently in two server i.e. primary server and secondary server as shown in Figure 1. Both the Clients subscribe Report Control Block (RCB) to the IEC 61850 Servers. The redundant clients receive the information related to online events and data from IEC61850 Server. Only the active IEC 61850 Client which is residing in primary server is allowed to update data in Database Server, (through database replication technique the primary server database is updated in Secondary server database).This maintain a unique database in both the servers and avoids duplication of data by restricting the data updation by the secondary IEC 61850 Client. The active IEC 61850 Client is decided by the driver mode of IEC 61850 Client. If the driver mode flag is set to PRIMARY then the IEC 61850 Client is in active state else if the driver mode flag is set to SECONDARY then the IEC 61850 Client is in Standby/Passive state. The driver mode flag in the IEC 61850 Client is decided by the redundancy manager. The switching over time from primary server to secondary server is around 500 ms considering all resources (Network, Application and Database) availability. To avoid the data loss during server switchover, each IEC 61850 Client has a provision to maintain a 5 sec data buffer.

3.7 Database:

My SQL 5.2 Version is used as Database for Substation Automation System. The replication is achieved by using the MySql Master-Master replication technique. Replication enables data from primary server database (the master) to be replicated to secondary server database (the slave). Replication is asynchronous - slaves need

not be connected permanently to receive updates from the master i.e. when a slave machine comes online the replication module in MySql takes care of the residual data updation in slave server database. Here both servers act in Active/Active mode. Replication architecture for two servers is shown in Figure 7.

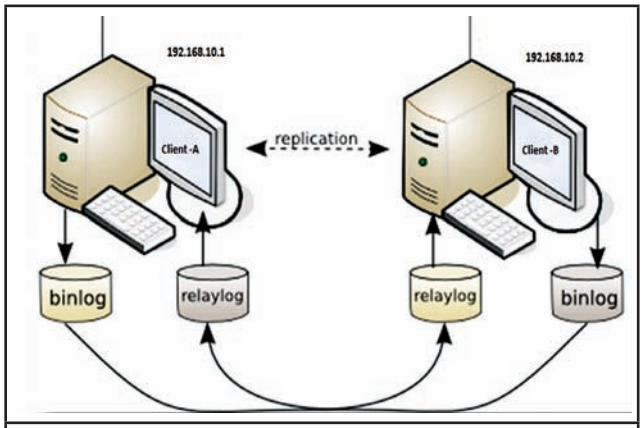

FIG. 7: REPLICATION ARCHITECTURE [7]

4.0 TEST RESULT AND ANALYSIS:

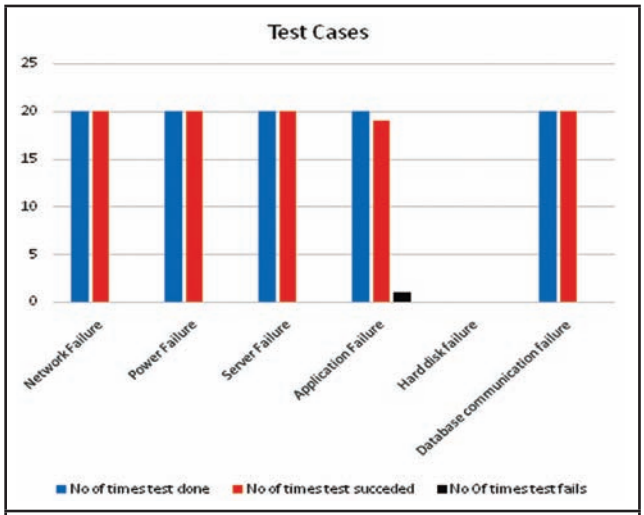

FIG. 8: BAR GRAPH FOR VARIOUS TEST CASES.

The redundancy manager application is tested with various failover (switching from primary to secondary and from secondary to primary server) conditions, the major failover conditions are Network Failure, Power Failure, Server Failure, Application failure, Harddisk failure and Database communication failure. Twenty number of tests for each condition is tested with this configuration the test results for each condition is given in the bar graph Figure 8. Harddisk failure condition is not simulated in this test. It is observed there is a 100% failover success on Network Failure, Power Failure, Server Failure, and Database communication failure. Whereas in case of application failure case one time failure is noticed out of 20 cases.

5.0 CONCLUSIONS:

In this paper a scheme is presented to implement system level redundancy solution in a substation automation network having IEC 61850 client. NIC Teaming, NIC binding, Low level Network Driver (NDIS) communication and Database replication technique are implemented to implement the solution for seamless IEC 61850 Client redundancy. The above solution provides a dual server redundancy architecture and the same can be extended to an N+1 server redundancy architecture.

ACKNOWLEDGEMENT:

The Authors thank BHEL management for extending all support in initiation of the pioneering research work in IEC 61850 area which is an emerging technology in the area of Substation automation. The authors express their sincere thanks for the support extended by different departments of R&D division in carrying out the product development and system integration. The authors also wish to express their sincere thanks to BHEL management for providing an opportunity to publishing the research work and to present a paper on the same.

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