

# Reliability Improvement of Radial Distribution System with Smart Grid Technology

E.Vidya Sagar and P.V.N.Prasad

**Abstract**—This paper describes the concept and characteristics of smart grid distribution systems, basic difference between conventional and smart grid distribution systems, functional management and reliability evaluation of smart grid distribution systems. In smart grid distribution system, remotely controlled high rated power electronic switches are used in the place of normal disconnecting switches on feeder. In normal operation of distribution system, these act as normally closed switches. Whereas, in faulted conditions, the computer system at the control center will sense the fault location through the sensors, digital controls, G.I.S and will turn off the power electronic switches to isolate the fault section and as well as operate other protective devices to restore the loads under the un-faulted in less than one cycle period to maintain high reliability of the distribution systems. In this paper, the reliability indices of a radial distribution system for (i) conventional (non-automated), (ii) automated and (iii) smart grid configurations are calculated and the results are compared.

**Index terms**—Distribution System, Distribution Automation, Reliability Indices, Smart Grid Technology, Remote Terminal Unit, RBTS

## I. INTRODUCTION

IN distribution automation, remotely operated disconnecting switches are used for the quick restoration of power supply to the loads which are under un-faulted sections of the feeder. Smart grid technology includes the application of DA and digital controls to the distribution system and this can lead to have much more faster restoration of the power supply in distribution systems [1]. Some of the important characteristics of smart grid technology are (i) distribution automation (ii) increase in use of digital control and information technology with real time availability (iii) deployment of smart meters and phase measurement units (iv) inclusion of demand side response and demand side management technologies (v) integration of renewable and energy storage facilities (vi) smart appliances and customer devices at the customer’s premises (vii) dynamic optimization relating to the grid operability (viii) advanced, composite and high temperature superconductors are used (ix) energy storage, batteries, flywheels and switched mode power supply technologies are used. The inclusion of smart metering, demand side response,

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demand side management, digital controls, smart appliances at the customer’s premises, power electronic converter switches, solid state transformers, renewable energy storages and effective sensors and dynamic optimization of power system, to the conventional distribution system make a smart grid distribution system. This results in increase in reliability, efficiency and safety of electrical distribution systems [2]. The vision of smart grid distribution system is shown in Fig. 1.

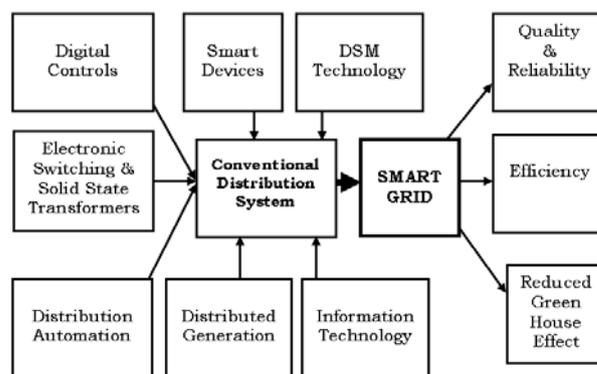


Fig.1. Vision of Smart Grid Distribution System

The differences between conventional and smart grid distribution system are shown in Table I.

TABLE I  
 DIFFERENCES BETWEEN CONVENTIONAL AND SMART GRID DISTRIBUTION SYSTEM

Sl.No.	Conventional Distribution Systems	Smart Grid Distribution Systems
1.	Radial topology	Network topology
2.	Electromechanical controls	Digital controls
3.	Built for centralized generation	Accommodates distributed generation
4.	Manual restoration	Self-healing
5.	Few /no sensors are used	Advanced sensors are used throughout the system for monitoring
6.	Emergency decisions are taken by committee and by phone	Decision support systems and predictive reliability is used
7.	Limited or no price information	Full price information
8.	Limited control over power flows	Full control over power flows
9.	It is not a self monitoring/blind system	It is a self monitoring system
10.	One way communication	Two way communication
11.	Prone to failures and blackouts	Adaptive protection and islanding is possible
12.	Equipments are checked and controlled manually	Equipments are checked and controlled remotely
13.	Few customers choice	Many customers choice
14.	Manual operated disconnecting switches are used	High rated power electronic switches are used

Some of the functional managements of smart grid distribution system are given below:

1. Distribution Automation: Remotely monitor and control operations
2. Energy Management Systems: Takes the data needs. End users versions analyze the from various parts of the distribution network to create a single picture for analyzing the loads and forecasting load and energy patterns of the industries, offices, commercial and other types of loads.
3. Geographical Information Systems: Displays the status of equipments, position of crews and status of the functioning of customer's appliances on maps.
4. Outage Distribution Automation: Remotely monitor and control operations.
5. Energy Management Systems: Takes the data needs. End users versions analyze the from various parts of the distribution network to create a single picture for analyzing the loads and forecasting load and energy patterns of the industries, offices, commercial and other types of loads.
6. Functioning management: Pinpoint problems, locate equipment, create work orders and dispatch crew.
7. Intelligent network agents: Gather data, make decisions about local switching, control functions and communicate with control centers.
8. Grid modeling, simulation and design: Tools to model complex grids, optimize design choices and view potential sequences.
9. Power system monitoring and control: Monitor minute to minute operations of distribution system and have automated operations to allow centralized control.

## II. POWER ELECTRONIC SWITCHING USED IN SMART DISTRIBUTION SYSTEMS

The sensitive loads of distribution system require a continuous power supply and they must be restored very quickly, if at all any interruption takes place. In smart grid distribution system, remotely operated high rated power electronic converter switches shown in Fig. 2 are used in the place of manual operated disconnecting switches [3][4].

Under normal operating conditions of the distribution system, the electronic switch is continuously turned on to work as a normally closed switch to supply the power to the customers. When a permanent active fault occurs, the voltage magnitude becomes zero, this will be detected in a very short time and the electronic switches are automatically turned off by remote operation, to isolate the faulty section and restore the load points under the un-faulted portion of the feeder [5][6].

The advanced sensors, communication technology and information technology used in the smart grid can detect the low voltage amplitudes in a very short time period of one quarter cycle. Since, the fault detection, isolation and restoration takes place in very short period of time of 16.7 ms for 60 Hz power supply, the reliability of distribution system increases very rapidly [5]. The dq0 transformation is used to

track the voltage magnitude in real time applications. The dq0 amplitude is used to initiate the circuit reconfiguration. Whenever dq0 amplitude is more than a specified value, the control center detects the fault location and turn-off the electronic switch placed on the feeder section to isolate the faulty section and restore the un-faulted section of the feeder [3].

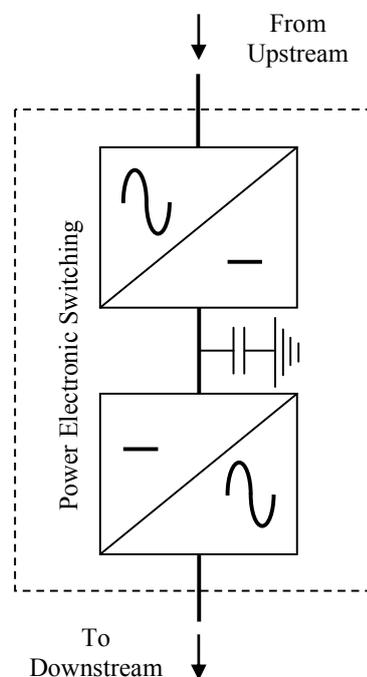


Fig. 2. Power Electronic Switching on 11 kV Feeder of Smart Grid Distribution Network

## III. RESTORATION PROCESS AFTER OCCURRENCE OF A SUSTAINED FAULT

This section describes the process of restoration after occurrence of the fault on anon-automated, full automated and smart grid radial feeder.

### A. Non Automated Feeders

In non-automated feeders all the disconnecting switches are manually operated switches.

- i). The CB will trip if fault occurs on any line segment or section. When this happens, a crew travels forward along the route of the circuit to find the location of fault.
- ii). After finding the location of fault, they open immediate upstream and downstream disconnecting switches to isolate the faulty section.
- iii). They reclose circuit breaker at substation to restore the upstream load points.
- iv). They close normally open tie line switch to restore downstream load points from alternative supply.
- v). The loads under the fault condition are restored after the repair/replacement of fault section.

The effect of manual operations is simulated by assuming that the load points in upstream and downstream restored in one hour and load points under the faulted section are restored in five hours [7].

**B. Automated Feeders**

In the fully automated feeders, all the disconnecting switches are motor operated switches

- i). The CB will trip if fault occurs on any line segment /section. When this happens, the fault signals are transmitted to the control center.
- ii). The computer system in control center detects fault location by checking each RTU.
- iii). When the fault section has been identified, the computer transmits a control signal to corresponding RTUs to operate disconnecting switches.
- iv). When the faulted section has been isolated, the computer transmits the control signal to RTUs to close the normally open tie-switch (TS) and reclose the circuit breaker, the load disconnected can be restored.
- v). The loads which are under the fault condition are restored after the repair/replacement of fault section [8]

The effect of automation operations is simulated by assuming that the load points in upstream and downstream restored in five seconds and load points under the faulted section are restored in five hours.

**C. Smart Grid Distribution feeder**

Under normal operating conditions of the distribution system, the electronic switch is continuously turned on to work as a normally closed switch to supply the power to the customers. When a permanent active fault occurs, the voltage magnitude becomes zero and this will be detected in a very short time [10][11]. The electronic switches are automatically turned off by remote operation, to isolate the faulty section and restore the load points under the un-faulted portion of the feeder.

The effect of smart grid feeder is simulated by assuming that the load points in upstream and downstream can be restored in 16.67 ms for 60 Hz power supply and load points under the faulted section are restored in five hours.

**IV. CASE STUDY**

This section describes the operating conditions and input data of a standard RBTS Bus-2 Radial distribution system shown in Fig. 3.

**A. Operating conditions of distribution system**

- a) Residential, commercial and government/institution loads are metered on the low voltage side and the transformer is utility property and included in the analysis. The small user loads are metered on the high voltage side and the transformer is customer property and not included.
- b) The feeders are operated as radial feeders but connected as a mesh through normally open sectionalizing points. Following a fault on a feeder, the ring main units permit the sectionalizing point to be moved and customers to be supplied from alternative supply points.
- c) The loading level of BUS (20 MW) only justifies a single supply point.

- d) All breakers in the system are identified.
- e) All the 11 kV feeders and laterals are considered either as overhead lines or as cables.
- f) Each 11 kV feeder and lateral is one of three types, the lengths being 0.6, 0.75 or 0.8 kM.
- g) The feeders consist of disconnecting switches on each feeder section, fuses at the starting point of laterals, alternate supply and the distribution transformer is restored by the repair process.
- h) All the disconnecting switches are 100% reliable.

The reliability indices such as load point indices (average failure rate, average repair time and average outage time) and system performance indices (SAIFI, SAIDI, ENS and ASAI) of an RBTS Bus2 distribution system for Non-automated, Automated and Smart grid distribution system are calculated [7]. The reduction in SAIDI indicates the improvement in reliability of the distribution system [8][9].

**B. System Data**

The electrical distribution system reliability analysis requires the length of feeders sections, feeder load points and customer data, location of switches on feeder sections and system reliability data [7]. They are shown in Table II, Table III, Table IV and Table V respectively.

TABLE II  
FEEDER'S SECTION LENGTH DATA

Length (kM)	Feeder section numbers			
	Feeder-1	Feeder-2	Feeder-3	Feeder-4
0.60	2,6,10	14	17,21,25	28,30,34
0.75	1,4,7,9	12	16,19,22, 24	27,29,32, 35
0.80	3,5,8,11	13,15	18,20,23	26,31,33,36

TABLE III  
FEEDER LOAD POINTS & CUSTOMER DATA

Load points	Type	Average Load/Customer (MW)	No. of Customers/ Load point
1-3,10,11	Residential	0.535	210
12,17-19	Residential	0.450	200
8	Small User	1.00	1
9	Small User	1.15	1
4,5,13,14, 20,21	Govt. Institute	0.566	1
6,7,15,16,22	Commercial	0.454	10

TABLE IV  
FEEDER SWITCHING LOCATIONS

Feeders	Location of a switch on Feeder Section		
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>
F <sub>1</sub>	4	7	10
F <sub>2</sub>	14	---	---
F <sub>3</sub>	18	21	24
F <sub>4</sub>	29	32	34

TABLE V  
SYSTEM RELIABILITY DATA

Component ratings (kV)	$\lambda_A$ (failures/yr.)	r (hr.)
Transformer 11/0.415	0.0150	200
Lines 11	0.0650	5

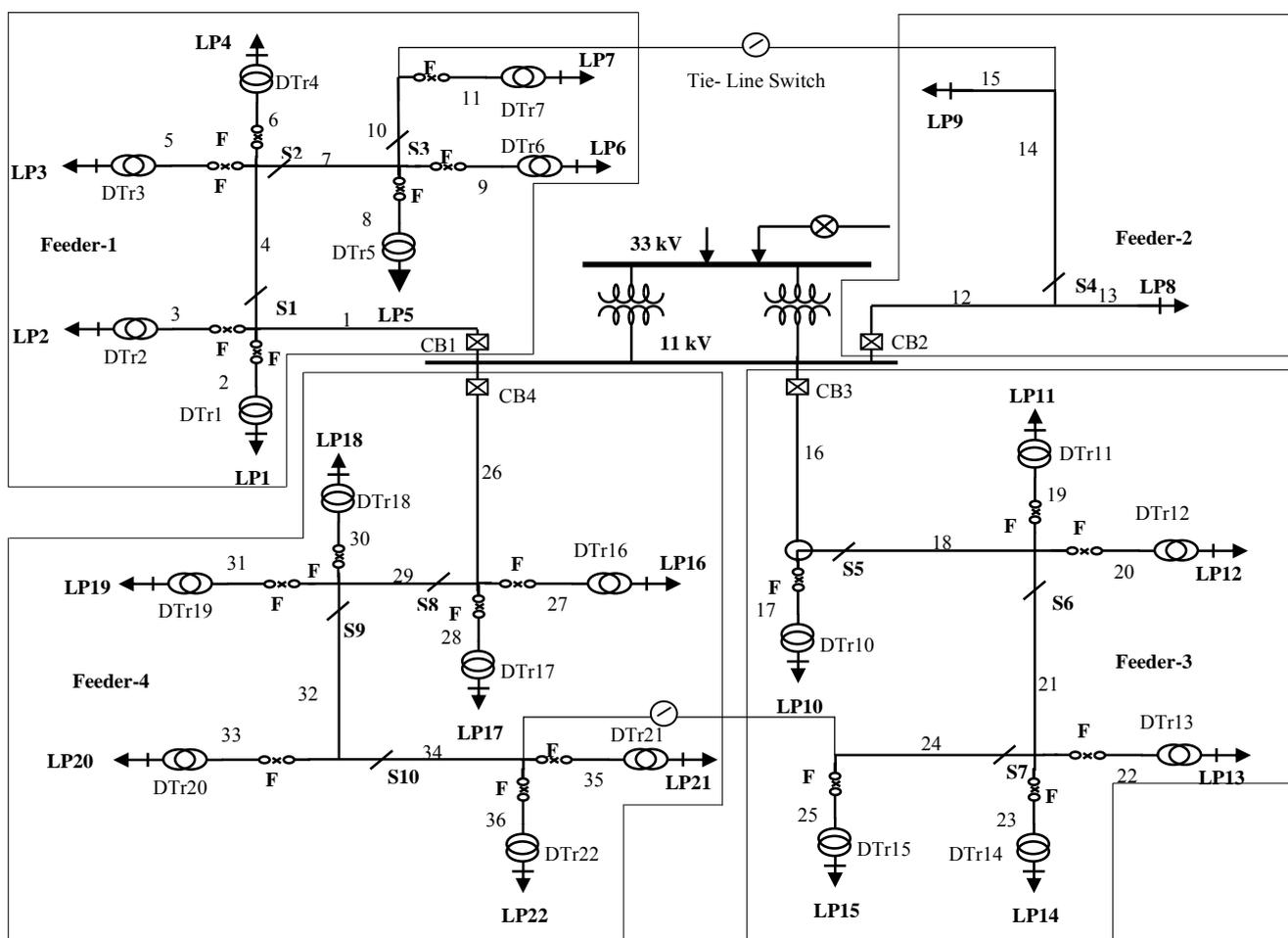


Fig. 3. Single Line Diagram of RBTS Bus 2 Distribution System

C. Results

The reliability indices of RBTS BUS2 such as SAIFI, SAIDI, CAIDI, ENS and ASAI calculated using failure mode effect analysis for each of the three cases. These results are shown in Table VI.

TABLE VI  
 SYSTEM PERFORMANCE INDICES OF FEEDERS AND SYSTEM FOR DIFFERENT CONFIGURATIONS

Configuration	Feeder	SAIFI	SAIDI	CAIDI	ENS	%ASAI
Non-Automated	1	0.2479	3.618	14.59	13.172	99.9587
	2	0.1400	0.520	3.74	1.120	99.9940
	3	0.2498	3.618	14.50	11.203	99.9586
	4	0.2470	3.605	14.59	12.248	99.9588
	System	0.2480	3.613	14.55	37.746	99.9588
Automated	1	0.2479	3.482	14.04	12.688	99.9599
	2	0.1400	0.479	3.420	1.030	99.9945
	3	0.2498	3.486	13.95	10.774	99.9602
	4	0.2470	3.466	14.03	11.758	99.9604
	System	0.2480	3.475	14.01	36.20	99.9603
Smart Grid	1	0.2479	3.481	14.04	12.67	99.9601
	2	0.1400	0.475	3.43	1.030	99.9945
	3	0.2498	3.475	13.95	10.76	99.9602
	4	0.2470	3.465	14.03	10.79	99.9604
	System	0.2480	3.457	14.00	36.23	99.9605

Fig. 4 shows the percentage reduction in SAIDI of all four Feeders and System for Automated and Smart-grid configurations when compared with Non-automated configuration.

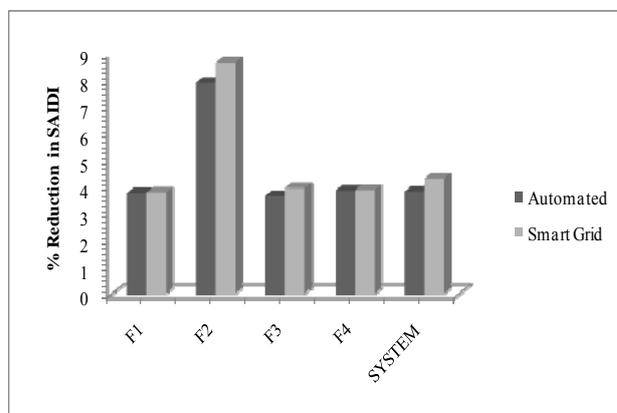


Fig. 4. Percentage Reduction in SAIDI of Feeders and Overall System

## V. CONCLUSIONS

The impact of smart grid technology on the reliability of radial distribution system is investigated. The smart grid technology improves the quality and reliability of power supply and also reduces the power losses. The fault detection, isolation and restoration process is very fast in the smart grid distribution system. The improvement in reliability of distribution system with smart grid technology is due to advanced sensors, digital controls, smart meters, power electronic switches and advanced communication system used in the system. The smart grid technology is applied and reliability indices of individual feeders and overall RBTS Bus 2 system are evaluated. The percentage reduction in SAIDI of feeders  $F_1$ ,  $F_2$ ,  $F_3$  &  $F_4$  and overall system are 3.8, 8.6, 3.95 & 3.9 and 4.32 respectively with respect to the corresponding non-automated systems.

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## NOMENCLATURE

- F: Feeder  
S: Switch  
U: Average Annual Outage (hr/yr)  
 $\lambda$ : Average failure rate (f/yr)  
Dtr: Distribution Transformer  
SAIFI: System Avg. Interruption Frequency Index (f/yr/cust.)  
SAIDI: System Avg. Interruption Duration Index (hr/yr/cust.)  
CAIDI: Customer Average Interruption Duration Index (hr/f)  
ENS: Energy Not Supplied (MWh/yr)  
ASAI: Average Service Availability Index  
RBTS: Roy Billinton Test System