The Impact of Distributed Energy Resources on the Reliability of Smart Distribution System

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ABSTRACT:
Reliability of power systems is a key aspect in modern power system planning, design, and operation. In many countries, electrical utilities are required to report annually the expected network performance. That report quantifies the expected reliability indices during the entire year such as the interruption frequency and the interruption duration. Various researches developed to assess the reliability of the power system. Furthermore, due to the widely growth of distributed energy resources (DER) that involves distributed generation (DG) and demand side management (DSM) in the electrical power system, investigating their impact on the system reliability becomes an attractive area for research. This paper discusses the influence of DG and DSM on a smart distribution system (SDS) by executing different case studies including; connection of DG to network at several locations and utilizing different DSM techniques. This research aims to quantify the reliability indices to evaluate the system reliability in different cases.

KEYWORDS: Reliability, Distributed Energy Resources, Distributed Generation, Demand Side Management, Smart Distribution System, DigSILENT.

1. INTRODUCTION

The essential function of the electrical power system is to deliver the electrical energy to its customers with an economic way and with acceptable level of quality and continuity [1]. In modern societies, electrical energy is expected to be continuously available when demanded. However, it is not possible at all times due to the random failures in the system which may be out of the control of the distribution network operators (DNOs) [2]. Electrical system involves very large and complex integrated systems. Thus, failure at any part of the system components can cause many interruptions for customers; these interruptions are varying from a small inconvenience for a small number of consumers to a catastrophic interruption of the supply (Blackout). Also, due to the widely growth of DER in the electrical power system [3], investigating their impact on the system reliability becomes mandatory.

The goal of DSM is to provide efficient use of the power system assets and reduce electricity costs for customers. In fact, DSM alters the load curves of consumers through a variety of programs, such as; peak clipping, load shifting, energy conservation, etc. Therefore, electric utilities are recommended to incorporate DSM in their resource planning by performing cost/benefit analysis. The promising infrastructure of the smart grid featuring real-time communication and data flow among electric utilities and consumers will support DSMs by providing more efficient load controllability and incentives based on dynamic electricity rates, in the near future. In addition, various researches also studied the impact of DSM on the system reliability; in [4] a new approach was developed to study the impact of DSM on the reliability of a composite transmission and generation systems. While in [5] authors studied the impact of applying different load management techniques on the individual load point and system reliability indices of a bulk electric power system. The impact of DG and DSM functionalities on the system reliability performance was evaluated in [6] by proposing a further modification in Monte Carlo Simulation.

This paper analyzes the reliability improvement effect of DG on a radial distribution system by comparing the system reliability indices before and after the connection of DG at several locations. A number of recent research studies have considered the impact of DG penetration on the system reliability; Authors in [7] presented a method to obtain the optimal operating strategy for DG incorporating the reliability worth assessment for the distribution system with taking into consideration the hourly reliability worth. While authors in [8] proposed a new technique that used a genetic algorithm to determine the optimal size and location for DG to improve the distribution system reliability with considering time varying loads. Researchers in [9] studied the distribution system reliability before and after inserting single and multiple DG units into the system at different locations. The different impacts of different DG locations on distribution system reliability were analyzed in [10] where RBTS Bus6 system was used to verify the proposed algorithm to calculate the reliability indices.

In this paper, we determine the influence of DG and DSM techniques (peak clipping, load shifting and energy conservation) on the reliability of a radial distribution system by using DigSILENT PowerFactory software.

This paper has been organized in the following way: Section 2 presents the reliability concept in distribution power system. Section 3 briefly defines the distributed energy resources. Section 4 includes the reliability assessment methodology that is utilized in this paper in addition to the reliability indices that are used to measure the system reliability. Section 5 describes RBTS Bus2 model that is used in case studies in this research. Section 6 summarizes the different case studies that are conducted in this paper. Results of different case studies are presented and discussed in section 7. The paper conclusion is stated in section 8.

2. RELIABILITY CONCEPT IN DISTRIBUTION POWER SYSTEM

Since the reliability term has a wide range of definitions, it is not easy to be related to only one definition specifically. It is necessary to consider this fact while defining this term in this paper. A general definition for the reliability term is the system ability to do its function satisfactorily [1].

While in power system, reliability means that the energy is transferred from generation facilities to the consumers through the transmission facilities without any interruptions. In fact, reliability in power system is considered as an imperative factor during the operation and the planning phases. Thus, it is essential to quantify the system reliability by monitoring some indicators and indices such as frequency and duration of interruptions at the customer load points, in addition to the whole system indices [1]. Since 90% of the customer reliability problems are coming from distribution system, more attention should be given to distribution system reliability studies to improve the whole system reliability [11].

3. DISTRIBUTED ENERGY RESOURCES

DER will significantly contribute in the reliability of RDS. DER includes the following [12]:

1- DG units such as; photovoltaic, wind turbines, fuel cells, micro turbines, rotating machines, etc. DG is a generation unit that is dispersed throughout the utility's service. It can be connected to distribution system or isolated from the grid. DG has many technologies such as; wind turbines, photovoltaic, micro-turbines and fuel cells [10].

2- Energy storage such as; batteries and capacitors.

3- DSM by modifying the load demand according to electricity price over time. In this paper, DSM techniques/programs are analyzed from electrical utility perspective. Since, DSM is defined as "the planning, implementation, and monitoring of distribution network utility activities designed to influence customer use of electricity in ways that will produce desired changes in the load shape". DSM has two components; "energy efficiency (EF) and demand response (DR)", EE is utilized to reduce the load demand during all hours, while DR is utilized to reduce the load demand during specific hours where the electricity prices are low. DSM implementation has many benefits for both utility and consumers [13].

The advantages of DR can be listed as follows: From the customer's point of view, it provides the ability to manage the consumption and save costs on electricity bills. From the market perspective, it helps eliminate or decrease the price spikes. Needless to say, from an operator point of view, it reduces the peak demand, thereby realizing operational and capital cost savings [14]. Furthermore, it may reduce the interruption costs that are paid by the utility to customers due to the supply interruptions.

4. RELIABILITY ASSESSMENT METHODOLOGY AND INDICES

DIgSILENT PowerFactory is an engineering software tool that is utilized to analyzing the power systems. It is advanced interactive and integrated software dedicated to power system analysis to achieve the objectives of the operation and planning optimization. DIgSILENT is an acronym for "DIgital SImuLation of Electrical NeTworks".

Many indices are used for evaluating the system reliability. IEEE has published countless standards in order to include reliability related key definitions and evaluation indices; IEEE Std. 1366 [18] concerns with the reliability indices in a distribution system, which are classified into two types; load point indices and system indices. However, this paper will only be shedding lights on the system indices that are described in Table 1 [17].

Table 1. The reliability system indices.

System Indices	Description	Unit
SAIFI	System Average Interruption Frequency Index	f/Cust./year
SAIDI	System Average Interruption Duration Index	hr/Cust./year
CAIDI	Customer Average Interruption Duration Index	hr
ASAI	Average Service Availability Index	P.U.
ENS	Energy Not Supplied	MWh/year
EIC	Expected Interruption Cost	M$/year
IEAR	Interrupted Energy Assessment Rate	$/kWh

Reliability system indices equations that are included in DigSILENT user manual [17] are listed below.

$$SAIFI = \frac{\sum ACIFi.Ci}{\sum Ci} \quad (\text{f/cust./year}) \tag{1}$$

$$SAIDI = \frac{\sum ACITi.Ci}{\sum Ci} \quad (\text{hr/cust./year}) \tag{2}$$

$$CAIDI = \frac{SAIDI}{SAIFI} \ (\text{hr}) \tag{3}$$

$$ASAI = 1 - \frac{\sum ACITi.Ci}{8760 \sum Ci} \ (p.u.) \tag{4}$$

$$ENS = \sum LPENS \quad (\text{MWh/year}) \tag{5}$$

$$EIC = \sum LPEIC \quad (\text{M\$/year}) \tag{6}$$

$$IEAR = \frac{EIC}{ENS} \quad (\text{\$/kWh}) \tag{7}$$

Where:

$$ACIFi = \sum_k Frk \cdot fraci,k \quad \left(\frac{\text{f}}{\text{year}}\right)$$

$$ACITi = \sum_k 8760 \cdot Prk \cdot fraci,k \ (\text{hr./year})$$

$$LPENSi = ACITi\,.(Pdi + Psi) \ \ (MWh/year)$$

$$LPIC = \sum_k LPEICi,k \quad (\text{\$/year})$$

The following parameters are used in defining the reliability indices:

Ci: Number of consumers which are supplied by load point i

Ai: Number of consumers which are affected with interruption load point i

Frk: Frequency of occurrence of contingency k

Prk: Probability of occurrence of contingency k

i: Load point index

k: Contingency index

$fraci$: Fraction of the load which is lost at the load point i, for contingency k.
For unsupplied loads, or loads that are shed completely, $fraci,$ = 1.0.
For loads that are partially shed, 0.0 <= $fraci,$ < 1.0.

Pdi: is the weighted average amount of power disconnected

Psi: is the weighted average amount of power shed at load point i.

5. SYSTEM UNDER STUDY

Roy Billinton test system RBTS Bus [19] is utilized to validate case studies that are performed as a part of this paper. The system has 20 MW peak loading level, it consists of one 33kV main bus which is connected to the external grid from one side and the other side is connected to 11kV supply point (SP) through two main transformers in parallel (16 MVA each). There are four main feeders (F1, F2, F3 and F4) at 11kV; these feeders operate as radial feeders and isolated by circuit breakers (C.Bs).

The system consists of 36 overhead lines, 22 load points and 20 distribution transformers (2MVA each) as depicted in Fig. 1. Feeder's length, customer data and component reliability data are shown in Tables 2, 3 and 4 respectively [19]. Calculating the cost of customer interruption is a good way to determine the system worth reliability which is depending on the client's characteristic. Customers are divided into seven categories of large users, small industrial users, commercial, Agriculture, residential, government & institutions and office & buildings [20]. Table 5 shows the interruption cost in $/kW for the four consumer sectors that are included in RTBS Bus2.

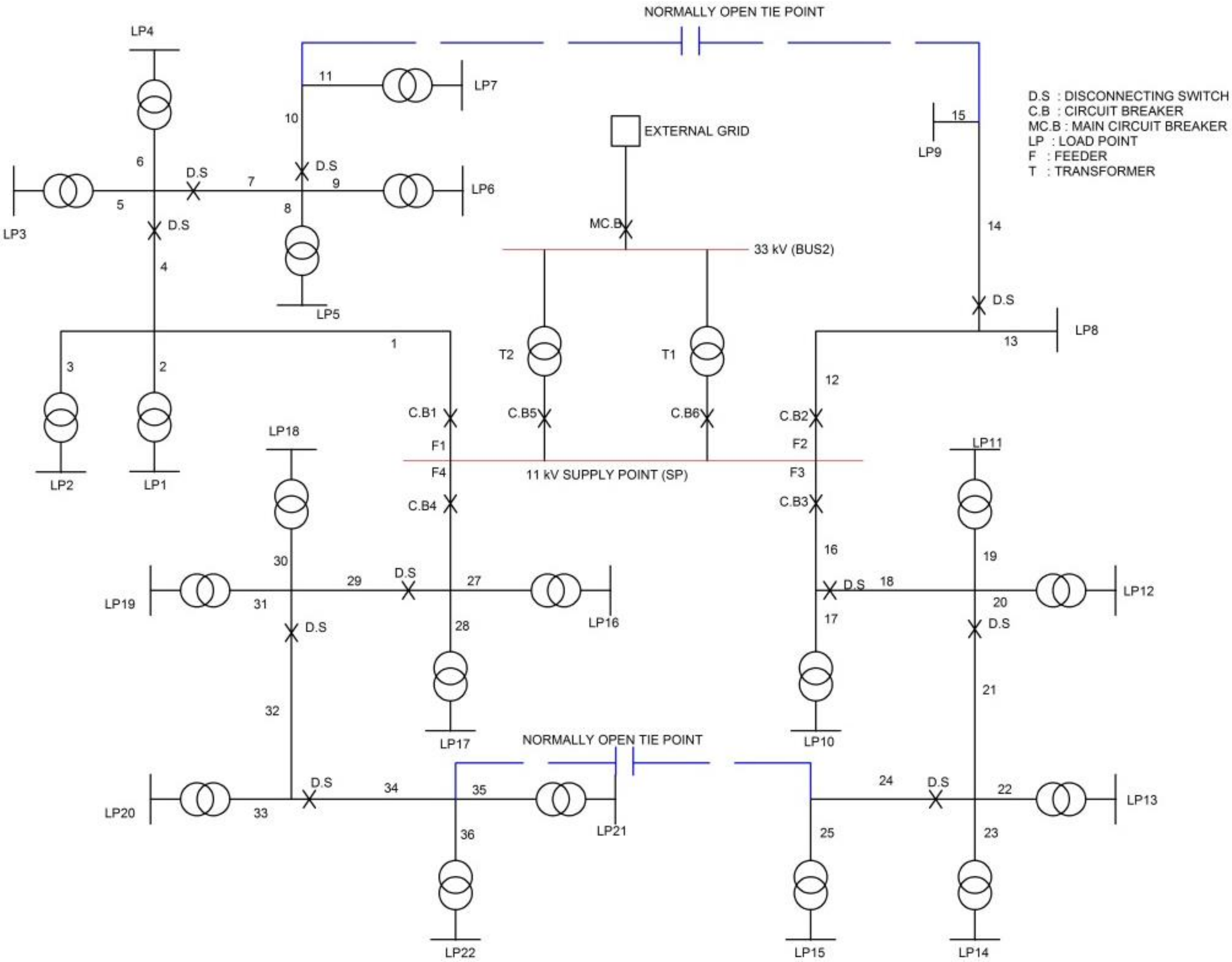

Fig. 1. RBTS Bus2 Distribution System.

Table 2. RBTS Bus2 Feeders Data.

Type	Length (km)	Feeder Section Numbers
1	0.6	2, 6, 10, 14, 17, 21, 25, 28, 30, 34
2	0.75	1, 4, 7, 9, 12, 16, 19, 22, 24, 27, 29, 32, 35
3	0.8	3, 5, 8, 11, 13, 15, 18, 20, 23, 26, 31, 33, 36

Table 3. The Costumer Types, Number and Load Data.

Load Point Number	Load Point Type	Customer Type	Average Load per Load Point (MW)	Peak Load per Load Point (MW)	No. of customers per Load Point
1, 2, 3, 10, 11	LP-A	Residential	0.535	0.8668	210
12, 17, 18, 19	LP-B	Residential	0.45	0.7291	200
8	LP-C	Small Industrial User	1	1.6279	1
9	LP-D	Small Industrial User	1.15	1.8721	1
4, 5, 13, 14, 20, 21	LP-E	Government/Institution G & I	0.566	0.9167	1
6, 7, 15, 16, 22	LP-F	Commercial	0.454	0.75	10
Total			12.291	20	1908

Table 4. Component Reliability Data.

Component	Failure rate (f/yr)	Replace/Repair Time (hr)
Transformer (33 / 11 kV)	0.015	120*
Transformer (11 / 0.4 kV)	0.015	200*
C.B (33 kV)	0.002	4
C.B (11 kV)	0.006	4
Busbar (33 kV)	0.001	2
Busbar (11 kV)	0.001	2
Lines (11 kV)	0.065	5

*: repair time (hr) is considered

Table 5. Cost of Interruption in $/kW for various sectors.

Duration (min)	Residential Sector	Commercial Sector	Small Industrial Users Sector	Govt. & Inst. Sector
1	0.001	0.381	1.625	0.044
20	0.093	2.969	3.868	0.369
60	0.482	8.552	9.085	1.492
240	4.914	31.317	25.163	6.558
480	15.69	83.008	55.808	26.04

6. CASE STUDIES STRUCTURE

Five (5) case studies are performed as a part of this paper summarized in Table 6.

Table 6. Case Studies Structure

#	Description
Case 1	Reference case study (The same as reference paper [19]).
Case 2	Case 1 with considering the following: - The failure rate of 33 kV components and 33/11 kV substations. - Adding two circuit breakers to isolate the two main transformers from each other. - The hourly load curve for all load points
Case 3	Case 2 with inserting DG unit at several locations in the network.
Case 4	Case 2 with applying various DSM techniques (peak clipping, load shifting and energy conservation) on all load points.
Case 5	Case 4 with connecting DG to the network.

This section comprises of different case studies. Numbers of assumptions (listed below) are taken up during the assessment for all case studies.

1- The system is regarded as a radial system.
2- Normally open feeder tie points in Fig. 1 are not considered.
3- Disconnects are thought to be 100% reliable.
4- It's assumed that all C.Bs operate successfully whenever required, also 11kV disconnects are opened successfully when required to isolate the fault.
5- Power supply will be restored to load points by using suitable disconnects and C.Bs.
6- All failures are deemed statistically independent.
7- Second order faults (double contingency) are not considered.
8- The external grid is considered to be 100% reliable.
9- Partial load shedding for load points is not considered.

A. Case 1

This case study aims to validate results from the developed RBTS Bus2 model in DigSILENT. The results of this case are compared with the reference results in [19] which include the same case study. During this case, two assumptions are considered:
1-Failure of Busbar/terminals, 33kV system components and 33/11 kV substations are neglected.
2- The average load for each load point in Table 3 is considered in the assessment.

B. Case 2

In order to increase the accuracy of the assessment that is performed in case 1, failures of

Busbars/terminals, 33kV system components and 33/11 kV substations should be considered during the assessment. Moreover, the current RBTS Bus2 configuration in Fig. 1 has a major problem that affects the system reliability. The two main transformers (T1 and T2) are connected directly to the 33kV bus without isolating C.Bs. Thus, if one transformer fails, it would lead the whole system to be de-energized. Needless to say, in order to mitigate this issue, RBTS Bus2 model modification is suggested in this paper. Accordingly, this modification is made by adding two circuit breakers (C.B7 & C.B8) to isolate the two transformers from each other as illustrated in Fig. 2.

Also, to make the assessment more practical, it is necessary to consider the hourly load curve during the year. In real networks, the load demand is fluctuating with respect to time since the distribution feeders are lightly loaded in midnight and early in the morning that is heavily loaded during certain hours of the day.

Since reliability assessment is performed for the entire year, the hourly load variation data at each load point during one year is imperative to perform an accurate assessment. However, due to the unavailability of this data for RBTS Bus2 distribution system, the hourly load curves could be developed during at least one day (24 hours) per each load point, by using average and peak load values that are shown in Table 3, considering the general load profile's shape shown in Fig. 3 [11] [21] [7]. These general load profiles vary according to the characteristics of the consumers, since it depends on the psychology of the customers, as well as their schedule of electricity usage [21].

The developed hourly load curves for all customer load points types (LP-A, LP-B, LP-C, LP-D, LP-E and LP-F) are presented from Fig. 4 to Fig. 9.

C. Case 3

In order to determine the reliability improvement effect of DG in the distribution system, this paper uses RBTS Bus2 system as a case study. The reliability indices are calculated before and after the connection of DG to the network. Meanwhile, different impacts of different DG locations on distribution system are analyzed as well, in order to select the most suitable location from the available DG locations. The DG impact on the system reliability depends on many factors, such as (DG mode of operation, DG type, DG location, number of DG units and DG size..… Etc.). In this case study, a number of assumptions (listed below) are considered during the assessment.

1- DG is connected to the distribution system with a C.B to isolate DG in case of fault occurrence.

2- To connect DG to the network, there are too many scenarios (may be unlimited). But due to the assessment limitations, we assume connecting a single DG unit to the network at several locations "eleven intersection points" (A, B, C, D, E, F, G, H, K, L and M) as shown in Fig. 2. These intersection points can be defined as switchgears that distribute power to different customer load points in the network. Each point has a different distance from SP as shown in Table 7. DG is inserted at a point then the reliability assessment is performed. After that DG is moved to another point and hence the assessment is performed again. Finally, we choose the optimum DG location by comparing the reliability indices between these different points.

3- DG is assumed to operate in islanding mode (it serves its loads in case of the absence of the main supply [22]). C.B that isolates DG is normally closed. While the C.B that isolates the relevant main feeder (C.B1, C.B2, C.B3 or C.B4 in Fig. 2) is normally open. For example, if DG is located at point A (Fig. 2), C.B that isolates DG will be closed while C.B1 will be open.

4- Fuel cell DG type is assumed to be used in this case study since it is a continuous fuel source, dispatchable, cheaper than renewable energy technologies and will be widely used in the DG market for many years [23].

5- Since DG unit shall be capable of serving all the connected loads even in peak load hours, in this case, DG's size is selected based on the peak of the served loads as presented in Table 7.

6- Cost of supplying, installing and operation of DG units is not considered.

7- Effect of DG on voltage, frequency, harmonic, power factor, reactive power, short circuit, flickering, losses are not considered

8- DG unit is considered 100% reliable, since our concern is only with the reliability of the distribution system and the contribution of the DG in improving the system reliability.

D. Case 4

In this case study, the paper assesses the impact of DSM techniques on the system reliability. DSM modeled in this research is based on the reduction of system electricity demand due to energy efficient strategies and alleviation of the peak load by shifting the demand to the off-peak hours. Three DSM schemes are implemented as a part of this case study; peak clipping, load shifting and energy conservation. These schemes are applied by modifying the customers load curves as described in equations (8 – 11).

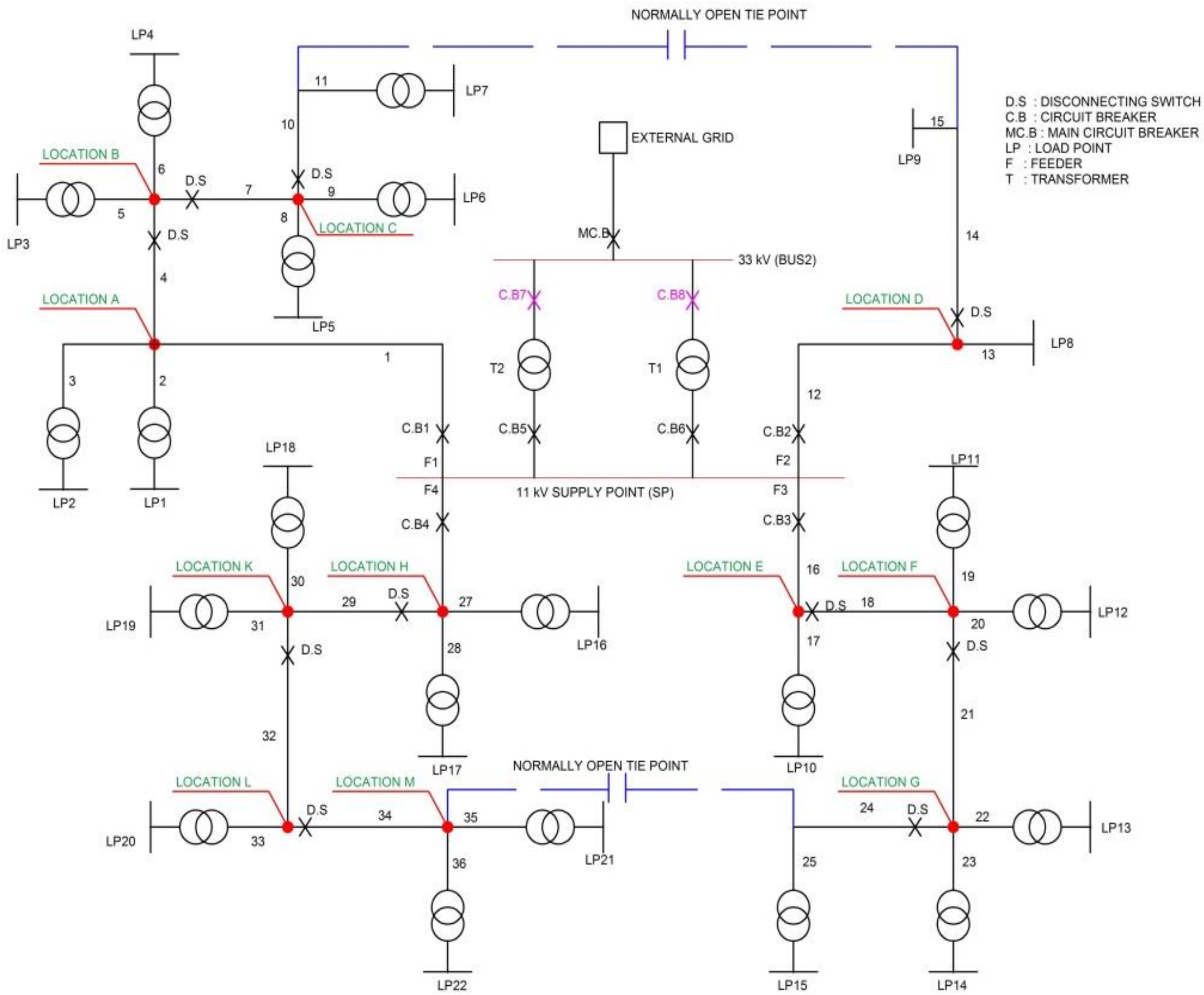

Fig. 2. The modified RBTS Bus2 model.

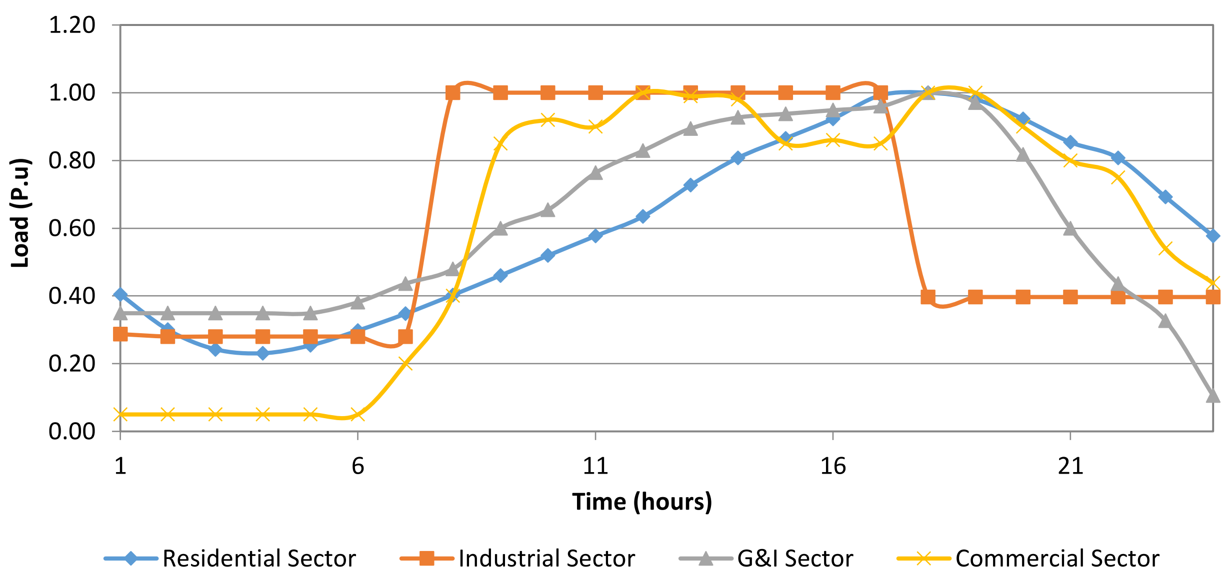

Fig. 3. Customer Sector's General Load Profiles.

Table 7. DG unit's capacity in islanding mode.

DG Location Point	Peak Load connected to this point (MW)	Selected DG Capacity (MW)	Distance from the supply point "SP" (km)
A	5.934	6	0.75
B	5.934		1.5
C	5.934		2.25
D	3.5	4	0.75
E	5.057	5	0.75
F	5.057		1.55
G	5.057		2.15
H	5.509	6	0.8
K	5.509		1.55
L	5.509		2.3
M	5.509		2.9

RBTS Bus2 system includes different types of customer's sectors; (Residential, Industrial, commercial and G&I) as described in Table 3. During this case study, we apply DSM techniques on all customer's types since we assume that each sector has some loads can be switched off without causing a major problem for the customer. Thus, hourly load curves for all customers' types are modified as showed from Fig. 4 to Fig. 9.

The impact of DSM on the system reliability is quantified by the reliability system indices in Table 1 and in equations (1 - 8), Since DSM techniques are represented by the modification in the customer's load curves, applying these techniques have no impact on some reliability indices such as the interruption frequency and the interruption duration. DSM is expected to affect the energy not supplied and the interruption cost indices.

i. Peak Clipping

Peak clipping or peak load reduction is a classical form of load management. In this technique, the load demand is limited to a pre-specified value [24]. The purpose of this case study is to evaluate the impact of peak clipping technique on the system reliability. This modification is applied by clipping the load peak to pre-specified value. The modified load value will be calculated using equation no. (8).

$$\overline{L(t)} = \begin{cases} L(t) & if\ L(t) < P \\ P & if\ L(t) > P \end{cases} \quad (8)$$

Where:

$\overline{L(t)}$: The modified load values

$l(t)$: The basic load values

P: pre-specified value

In this case study, the research assumes the pre-specified value is 80% of the peak load value. This modification is applied on the hourly load curves of each load point as showed from Fig. 4 to Fig. 9.

Peak Clipping 80% indicates that the load at each load point is clipped at 80% of its original peak load [25].

ii. Load Shifting

Load shifting is a classical form of load management forms, in which it combines the peak clipping and the valley filling techniques [24]. By using this DSM scheme, the loads are shifted from on-peak to off-peak hours. Though, on one hand, the peak load is shaved; however, on the other hand the load curve valley is filled. Accordingly, the purpose of this case study is assessing the impact of load shifting DSM technique on the system reliability. The modified load value will be calculated using equations no. (9) and (10).

$$\overline{L(t)} = \begin{cases} p & t \in \Omega \\ l(t) + A & t \in \psi \end{cases} \quad (9)$$

$$A = a\ \left[\frac{\sum_{t \in \Omega}(L(t) - P)}{N}\right] \quad (10)$$

Where:

$\overline{L(t)}$: The modified load value

$l\ (t)$: The basic load value
P: pre-specified value
ψ : Set of the off-peak hours during it the load will be raised.
Ω: Set of the on-peak hours during it the load will be reduced.
A: KW load added to each of f-peak hours of ψ .
N: Number of off-peak hours' in ψ.
a: The percentage of the energy reduced during the on-peak hours and recovered during the off-peak hours, which depend on the customers' need for energy during off-peak hours. However, in this case study, we assume (a = 1) which means that all clipped energy during on-peak hours are recovered during off-peak hours.

In the latter, it is assumed that the pre-specified value is 80% of the peak load value. This modification is applied on the hourly load curves of each load point as shown from Fig. 4 to Fig. 9.

Load shifting 80% indicates that the load at each load point is clipped at 80% of its original peak load and this clipped load (20% of the original peak load) is transferred to off-peak hours [25].

iii. Energy Conservation

The purpose of this case study is to assess the impact of energy conservation DSM technique on the reliability of the system. Energy Conservation is a form of load management which involves a reduction in the demand load with a definite reduction percentage from the demand load [26].

The system configuration is similar to the case study of 5D, but with modifying the hourly load curve of load points, by multiplying the basic load with the percentage of the energy reduction. This technique is modeled using equations no. (11) [4].

$$\overline{L\ (t)} = \begin{cases} L\ (t) + bB & t \in [t3, t4] \\ L\ (t) & t \in others \end{cases} \quad (11)$$

Where:
$\overline{L\ (t)}$: The modified load value
$l\ (t)$: The basic load value
B: MW load reduced to each hour between t_3 to t_4.
b: either +1 or –1, b=+1 refers to strategic load growth; b= –1 refers to strategic conservation

This modification is applied on the hourly load curves of each load point as shown from Fig. 4 to Fig. 9 where. Energy conservation 80% indicates that the load at each load point is decreased to 80% of its original value [25].

E. Case 5

In this case study, the impact of a combination of DG and DSM techniques on the system reliability is studied. As a result of case 3, the highest improvement in the reliability indices is occurred when DG is connecting at location "M". So in this case study, it is assumed that DG unit is connected to the network at location "M" as shown in Fig. 2 and different DSM techniques are applied (peak clipping, load shifting and energy conservation).

7. RESULTS AND DISCUSSIONS

Table 8 presents the results of the reliability system indices for all cases which are performed as a part of this paper.

As shown in Table 8, the calculated system indices in case 1 are matched with the system indices in the reference paper [19]. This validates the developed RBTS Bus2 model in this paper

Table 8 indicates in case 3, when connecting DG to any point at a certain feeder, the interruption frequency index (SAIFI) does not change because it reflects the number of outages during a year and it does not depend on the DG connection. For instance, if DG is connected to point (A, B or C) that are connected to main feeder F1, SAIFI has the same value for the three points. This result is expected since each feeder has only one C.B that isolates DG in case of any fault occurs at any point on the feeder.

It can be clearly observed from Table 8 that the best improvement in reliability indices occur when connecting DG to point "M" since ENS is improved from 149.237 MWh/year to 119.180 MWh/year, this saves about 30 MWh/year which decrease the interruption cost by (0.927-0.742) = 0.185 M$/year.

As noticed from Table 8; applying peak clipping, load shifting and energy conservation techniques do not seem to have any impacts on both the interruption frequency and the interruption duration. However, it reduces ENS and the interruption cost that is paid by the utility to consumers. The above results are expected since partial load shedding is not considered during RA and according to equations no. (1 & 2), neither the interruption frequency nor the interruption duration is depending on the demand load. However, they are depending on other factors such as the number of served customers, the frequency of contingency occurring, the probability of contingency occurring and the number of the customers affected by the contingency [17].

More improvement in reliability system indices is observed when applying DSM techniques with connecting DG unit to the network at location "M".

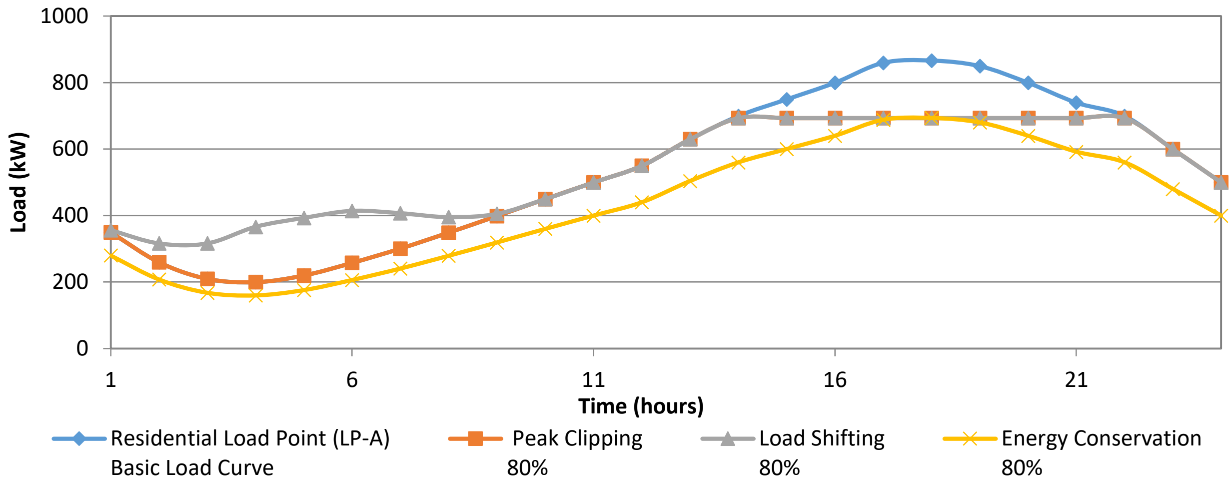

Fig. 4. Modified Hourly Load Curve for Residential Load Point (LP-A) After Applying Various DSM Techniques.

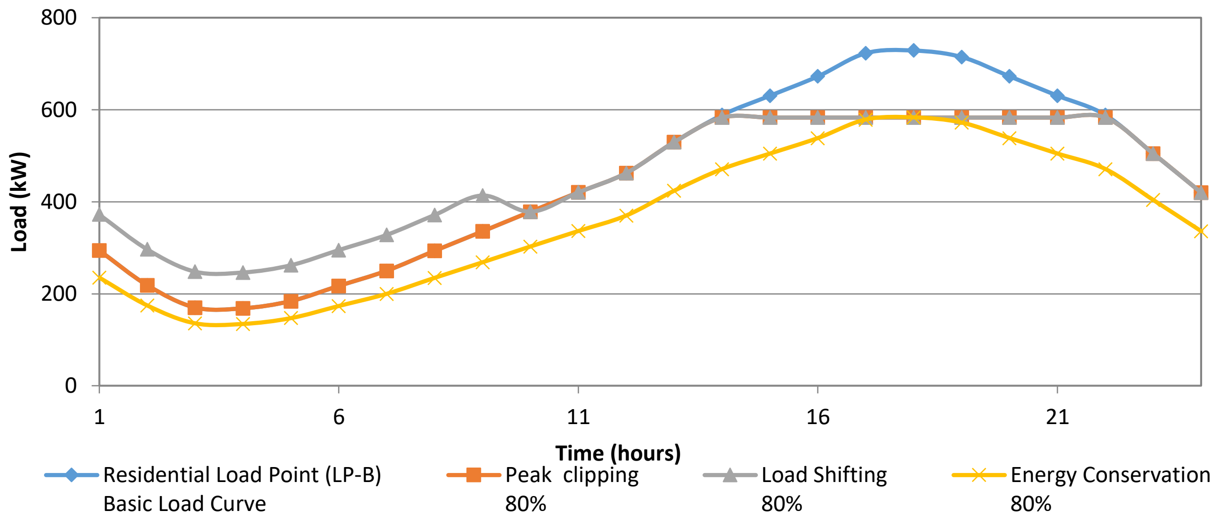

Fig. 5. Modified Hourly Load Curve for Residential Load Point (LP-B) After Applying Various DSM Techniques.

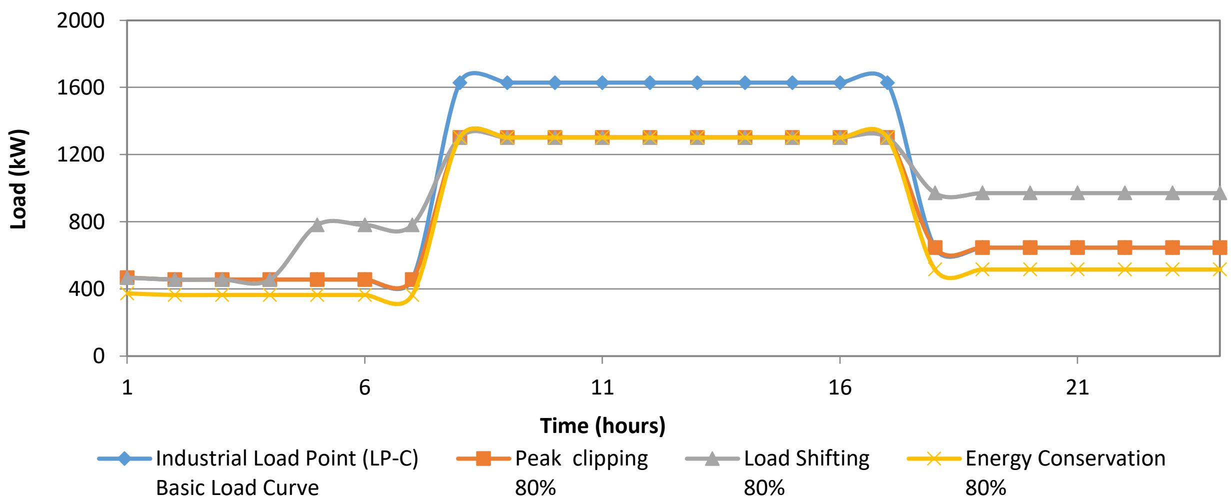

Fig. 6. Modified Hourly Load Curve for Industrial Load Point (LP-C) After Applying Various DSM Techniques.

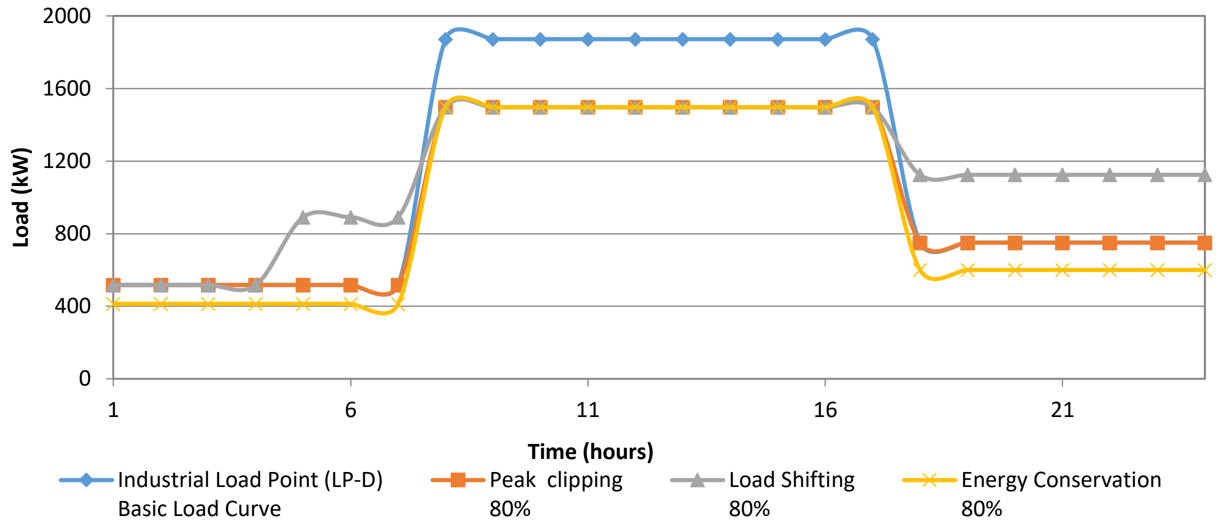

Fig.7. Modified Hourly Load Curve for Industrial Load Point (LP-D) After Applying Various DSM Techniques.

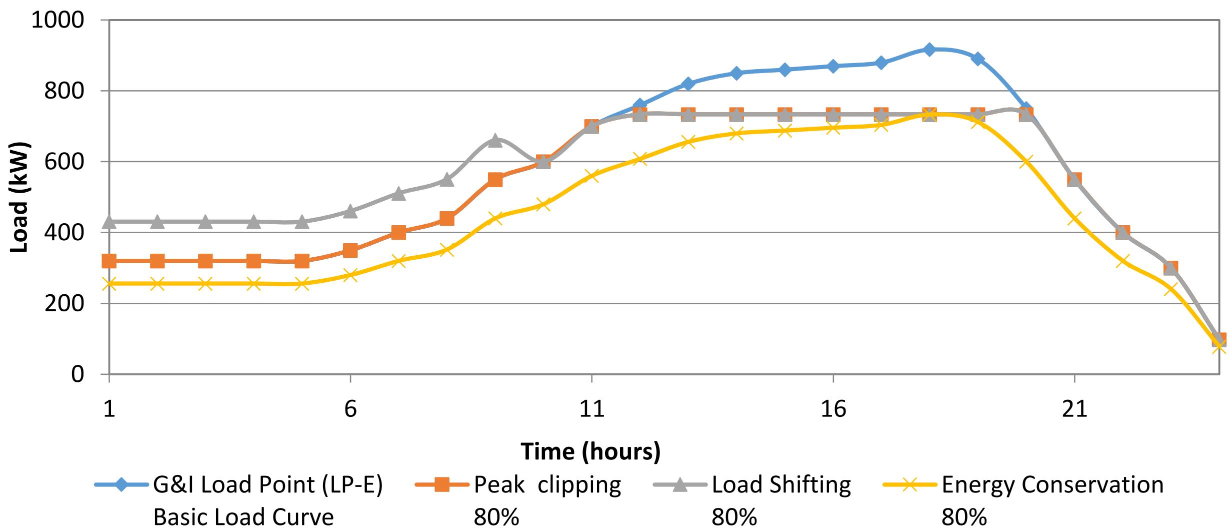

Fig.8. Modified Hourly Load Curve for G&I Load Point (LP-E) After Applying Various DSM Techniques.

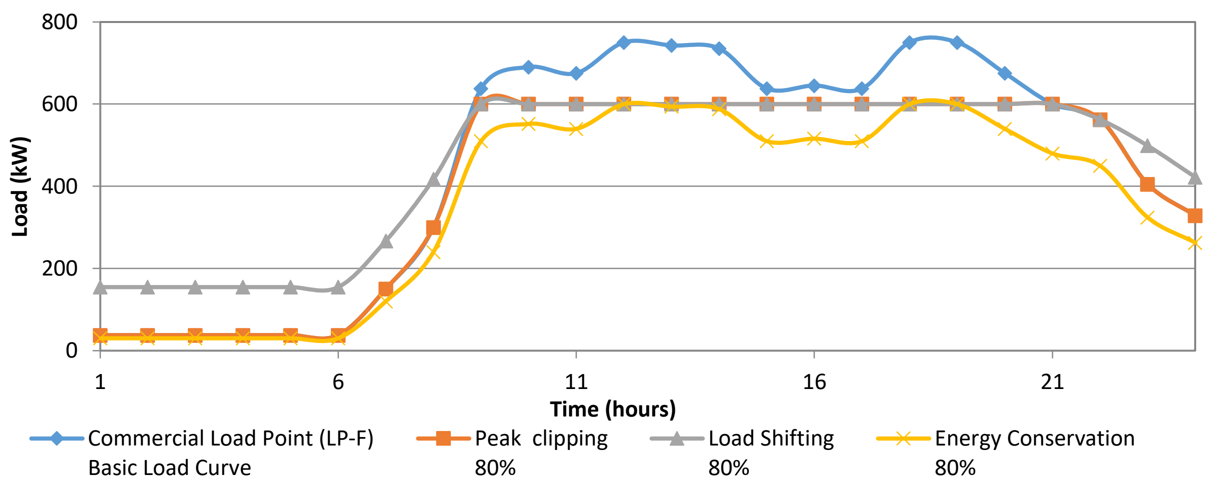

Fig.9. Modified Hourly Load Curve for G&I Load Point (LP-E) After Applying Various DSM Techniques.

Table 8. Reliability System Indices Results for all Cases

Case Studies	System Indices	SAIFI (f/Cust./ year)	SAIDI (hr/Cust./ year)	CAIDI (hr)	ASAI (p.u.)	ENS (MWh/ year)	EIC (M$/ year)	IEAR ($/ kWh)
System Indices in Reference Paper [19]		0.602	9.93	16.49	0.998866	149.188	-	-
Case 1		0.602	9.93	16.49	0.998866	149.188	0.927	6.214
Case 2		0.604353	9.938	16.444	0.998865	149.237	0.927	6.213
Case 3 (DG)	A	0.60367	9.936	16.459	0.998866	149.221	0.927	6.213
	B	0.60367	9.142	15.144	0.998956	132.407	0.81	6.115
	C	0.60367	9.07	15.025	0.998965	122.784	0.719	5.852
	D	0.604351	9.937	16.443	0.998866	149.225	0.927	6.213
	E	0.603691	9.936	16.459	0.998866	149.222	0.927	6.213
	F	0.603691	9.198	15.237	0.99895	140.645	0.883	6.275
	G	0.603691	9.157	15.168	0.998955	130.207	0.811	6.228
	H	0.603701	9.936	16.459	0.998866	149.221	0.927	6.213
	K	0.603701	8.526	14.123	0.999027	132.99	0.841	6.321
	L	0.603701	8.485	14.055	0.999031	122.635	0.769	6.274
	M	0.603701	8.446	14.023	0.999034	119.18	0.742	6.223
Case 4 (DSM)	80% Peak Clipping	0.604353	9.938	16.444	0.998866	145.318	0.9	6.191
	80% Load Shifting	0.604353	9.938	16.444	0.998866	149.244	0.927	6.123
	80% Energy Conservation	0.604353	9.938	16.444	0.998866	119.395	0.742	6.213
Case 5 (DG + DSM)	80% Peak Clipping + DG at location “M”	0.603701	8.446	14.023	0.999034	109.59	0.674	6.152
	80% Load Shifting + DG at location “M”	0.603701	8.446	14.023	0.999034	119.18	0.742	6.223
	80% Energy Conservation + DG at location “M”	0.603701	8.446	14.023	0.999034	95.344	0.593	6.223

8. CONCLUSION

In conclusion, the paper tackled the impact of DG connection and applying DSM techniques on the reliability of the distribution system. In addition, it proposed a modification in the distribution test system RBTS Bus2 configuration. Furthermore, the paper considered the customer's hourly load variation during the assessment. Finally, the following conclusions shall be deduced from the course of this present study.

RBTS Bus2 was used to validate the developed model in this paper.

As a result of case 3, inserting a DG unit would improve the system reliability; this improvement is depending on the location of the DG in the network. If the DG unit locates beside load points, it will result in a high improvement in the reliability.

Applying DSM techniques did not affect the interruption frequency or the interruption duration since these indices are depending on other factors such as the number of served customers, the frequency of contingency occurring, the probability of contingency occurring and the number of the customers affected by the contingency.

Applying peak clipping and load shifting technique reduced the ENS and the interruption cost while applying load shifting technique has no impact on the reliability indices.

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