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RESEARCH ARTICLE

THE CLOUT OF LOAD ADMINISTRATION AND RENEWABLE DG ON THE SERVICE RESTITUTION OF IMMINENT POWER DISTRIBUTION SYSTEMS

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ABSTRACT

Power reliability and restoration are considered significantly challenging issues in the development of future smart grids. Different characteristics can impact the reliability and restoration process of the future power distribution system. Two of the main characteristics of future smart grids are the integration of hybrid renewable resources and the implementation of load-side management (LM) programs. In this paper, the impact of integrating wind and solar energies and also the application of LM programs on the reliability and restoration process is examined. Two LM programs are considered, load shifting and peak clipping. The system under study is part of the RBTS Bus 2, and SAIDI, SAIFI, and ENS system reliability indices are computed.

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INTRODUCTION

The power restoration process is considered a major factor in system reliability. To achieve a satisfactory level of reliability, power restoration must be fast, secure and reliable in cases of interruptions or blackouts. One key influence that can improve service restoration and network reliability is the integration of distributed generators (DGs) into the grid. There are many advantages that can be achieved by the use of DGs (Jenkins *et al*., 2010; Adibi *et al*., 1994; Gözel and Hakan Hocaoglu, 2009; Adibi *et al*., 1992; Glover *et al*., 2010). Specifically, in service restoration, DGs can assist the utility in black-starting by providing extra power to the grid. Another option for network operators, in case of a blackout, is to implement intentional islanding for local loads with connected DGs and thereby decreasing the total demand on the utility and easing the black-starting process especially when there is no enough capacity from the utility. DGs can also enhance the voltage profile during restoration and avoid any voltage sags that my affect the power quality and reliability or may cause extra interrupted loads.

Moreover, Renewable based DGs are effective in reducing environmental pollution, and improve energy utilization efficiency and reliability, making them popular for use in the network (Huang Wei *et al*., 2011). Load Management (LM) can be defined as any action taken by the customer and/or the electricity supplier to reduce total system peak load, increase load factors, or improve the generation, transmission, distribution capacity or utilization of valuable resources (Leonardo Energy, 1996). This is usually achieved by increasing the price of electricity at peak times and reducing it at times when demand is low, which smooth out the load profile. It is worth mentioning that the purpose of LM is not necessarily to reduce total energy consumption but, in some cases, to shift loads from peak to off-peak times. As stated previously, DGs and renewable energy (RE) play an important role in the restoration process in microgrids. This is due to their ability to serve loads connected nearby. However, if the capacity of the DG or the current output of RE resources is relatively low during a failure, far connected loads will not be restored. This issue can be solved through controlling the loads by applying LM actions. An operator can find and apply an optimum load management scheme that is able to restore more loads and minimize the interruption cost. Furthermore, operators can forecast RE outputs and implement LM programs

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based on the forecasted results. Thereby, increasing the efficiency in harvesting RE resources which will definitely improve the restoration process due to the load-RE power output matching. This may also element and avoids expected faults from occurring. Hence, the combination of LM and RE becomes a crucial mater.

Several papers in the literature propose different methodologies in evaluating the impact of DGs on network reliability and service restoration. An interesting approach based on Analytical Simulation (AS) was presented in (Neto *et al*., 2006). The impact was assessed by comparing the isolated to the interconnected operation of DGs. The study showed that DGs can effectively reduce interruption duration, improve load point reliability in distribution systems, and eliminate network constraints violations. Many researchers have studied the effect of load management (LM) on the evaluation of reliability from different points of view. Reference (Dange Huang) examined the effect of selected load management techniques on the individual load point and system reliability indices of a bulk electric power system. The authors concluded that the system becomes more reliable and secure when applying effective DSM measures. Although several papers have studied the impact of RE and DSM separately on the reliability and restoration, the literature still lacks studies including both DSM and RE. In this paper, the impact of integrating wind and solar energies and the application of LM on the reliability and restoration process of the grid is examined. Actual RE data have been used. Also, two LM programs are considered and modeled, load shifting and peak clipping. The system under study is a part of RBTS Bus 2, and SAIDI, SAIFI, and ENS system reliability indices are computed. The simulation study covers an entire year.

System modeling

A. Annual Chronological Load Modeling

Hourly load data for an entire year is constructed using weekly, daily, and hourly factors that simulate load behavior. The following equation is used to simulate the load for different sectors, including residential, governmental/ institutional, commercial, and small industrial (Allan *et al*., 1991):

$$Load(t) = P_h \times P_d \times P_w \quad (1)$$

where *Load(t)* is the load value at hour *t* in per unit (p.u.), *Ph Pd*, and *Pw* are the hourly, daily and weekly load factors, respectively, for hour *t* in the year.

After generating the hourly load data for a complete year, the times of fail incidents are simulated using the inverse transformation method with the assumption that the failures follow an exponential distribution. The equation used to simulate the failures in the system is given as:

$$T = -ln(1-U)/\lambda \quad (2)$$

where T is the hour of failure, λ is the failure rate, and U is a random value uniformly distributed over the interval (0-1).

B. Wind Power Output

Practically speaking, the power output of a wind turbine depends mainly on the speed of the wind which can be expressed by the following sub-functions (Huang Wei *et al*., 2011):

$$P_{\text{out}}(v) = \begin{cases} 0, & v \le v_{ci} \cup v \ge v_{co} \\ P_{\text{R}} \dfrac{v^3 - v_{ci}{}^3}{v_R{}^3 - v_{ci}{}^3}, & v_{ci} < v < v_R \\ P_{\text{R}}, & v \ge v_R \end{cases} \quad (3)$$

where *v* is the wind speed, *vci* is the cut-in speed (minimal speed for output power), *vR* is the rated output speed, *vco* is the cut-out speed (maximum speed for outputting power), *PR* is the rated output power, and *Pout* is the output power of the wind turbine.

For this study, actual hourly wind speed data were analyzed to extract wind power output. Fig. 1 shows the simulated wind speed data in a Weibull distribution function. Note that the Weibull PDF was simulated only to provide a general overview about the behavior and probabilities of the studied wind speed. Equation (3) was used to convert the actual wind speed into power output.

C. PV Power Output

Power output from PVs is influenced by many external factors such as ambient temperature and sunlight intensity. A simplified equation relating sun irradiation to PV power output is (Huang Wei *et al*., 2011):

$$P_{out} = P_{STC} \frac{G_{AC}}{G_{STC}} \quad (4)$$

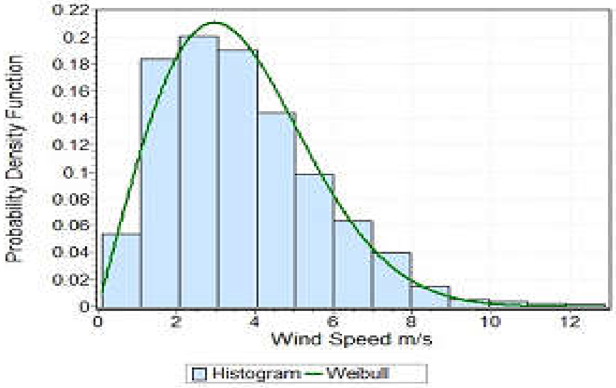

Fig. 1. Weibull distrubution for wind speed

Where *PSTC* is the maximum test power for the standard test conditions (STC) (intensity of sunlight of 1,000W/m2 and ambient temperature of 25° C); *GAC* is the intensity of the light; and *GSTC* is the light intensity for the STC. Actual solar irradiation data where used in this study. Fig. 2 shows the monthly averaged solar irradiation of the simulated year.

Equation (4) was used to convert the solar irradiation into power output.

D. Modeling Demand Side Management (DSM)

DSM is a general term to mean the modification of consumer demand using methods such as financial incentives and consumer education. It has been realized that DSM could= increase the quality and reliability of electricity in addition to saving money (El. Et-Tolba *et al*., 2013). Two principal DSM measures will be considered in this study, load shifting (LS) and peak clipping (PC).

1) Load Shifting (LS) Method

Load shifting is the process of moving loads from peak to off-peak times independent of total energy demand. In this paper, load shifting is simulated by a process of comparing and shifting N times for all load points where N represents the effectiveness of the load shifting. The simulation algorithms are as follows:

Step 1: comparing $L(t)$ with $L(t-1)$
If $L(t) < L(t-1) \rightarrow L(t) = L(t) + \varepsilon\times L(t-1)$
$L(t-1) = L(t-1) - \varepsilon\times L(t-1)$
If $L(t) \geq L(t-1) \rightarrow$ no change
Step 2: comparing $L(t)$ with $L(t+1)$
If $L(t) < L(t+1) \rightarrow L(t) = L(t) + \varepsilon\times L(t+1)$
$L(t+1) = L(t+1) - \varepsilon\times L(t+1)$
If $L(t) \geq L(t+1) \rightarrow$ no change

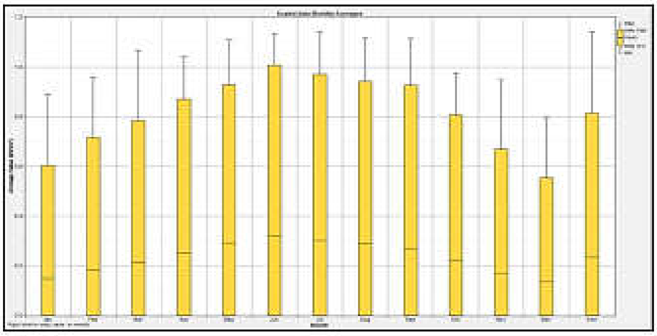

Fig. 2. Monthly averaged solar irradiation for the simulated year

where $L(t)$ is the load at hour t in p.u., ε is the shifting amount per step chosen to take the value of 0.01. The two steps are simulated for all t chronologically and load values are updated after each step. The whole process is repeated N times. Fig. 3 shows the load before and after load shifting with different values of N. The number N will be referred to as "shifting factor" in the rest of the paper. As seen in Fig 3, as the value of N increases, a larger amount of the load is shifted. If N is further increased (raising the load shifting effect), the load will eventually be almost constant, which is what utilities are striving to achieve to ensure higher reliability and less generation cost.

2) Peak Clipping (PC) Method

Unlike with the load shifting method, the peak clipping method aims to reduce the total energy demand. Load values that are considered to be peaks are clipped and brought down to a certain level. The peak clipping effect is determined by how peaks are defined. In this study, different cases were examined in which the peak was defined to be a factor of the load average. The range of that factor (referred to as "clipping factor (C)") was taken to be 1.1-1.3. The following equation illustrates the clipping procedure:

$$L^{PC}(t) = \begin{cases} L(t), & L(t) \leq A\times C \\ A\times C, & L(t) > A\times C \end{cases} \qquad (5)$$

Where $L^{PC}(t)$ is the load at hour t after peak clipping, A is the load average, and C refers to the clipping factor. Fig. 4 shows the load curve before and after peak clipping with the changing clipping factor. Clearly, as the clipping factor increases, less total energy is conserved.

E. RBTS-BUS 2 Distribution System

The RBTS-BUS 2 distribution system has been used frequently in the literature to study system reliability (10). The system is radial in nature and supplied by two 33/11 kV, 16 MVA transformers. Both high voltage and low voltage customers are included in the distribution system, where the 0.415 kV low voltage customers are supplied via 11/0.415 kV transformers and the 11 kV customers are supplied directly. For the purpose of this study, only loads connected to feeders1 and 2 are considered. A total of 9 load points consist of various types of customers. In general, the customers are divided into four groups: residential, governmental/institutional, commercial and industrial. Additionally, it is assumed that the normally open switch (NO) connecting load point 7 to load point 9 is an automated switch that will automatically close immediately at interruption of one of the two feeders. Fig. 5 shows the studied distribution system, and Table I presents additional information about the load points.

Reliability impact of hybrid renewable dg and load management

The reliability evaluation of the RBTS-BUS2 system indicated previously will be performed. The system will be studied during a restoration process and evaluated in terms of SAIFI, SAIDI and ENS indices. To include the transfer capacity of the system in this study, the voltage profile level for the connected loads will be analyzed. If the voltage drops below 0.95 p.u., the load will be considered lost or disconnected. The methodology of studying DGs and LM impacts on system reliability evaluation is as follows:

1. Modeling the loads using equation (1).
2. Interruption simulating using equation (2).
3. Calculating system reliability indices and recording lost LP (evaluating system reliability).
4. Integrating renewable DGs.
5. Re-evaluating system reliability.
6. Applying LM techniques to load curves excluding DGs.
7. Re-evaluating system reliability.
8. Applying LM techniques including renewable DGs Integration.
9. Re-evaluating system reliability.

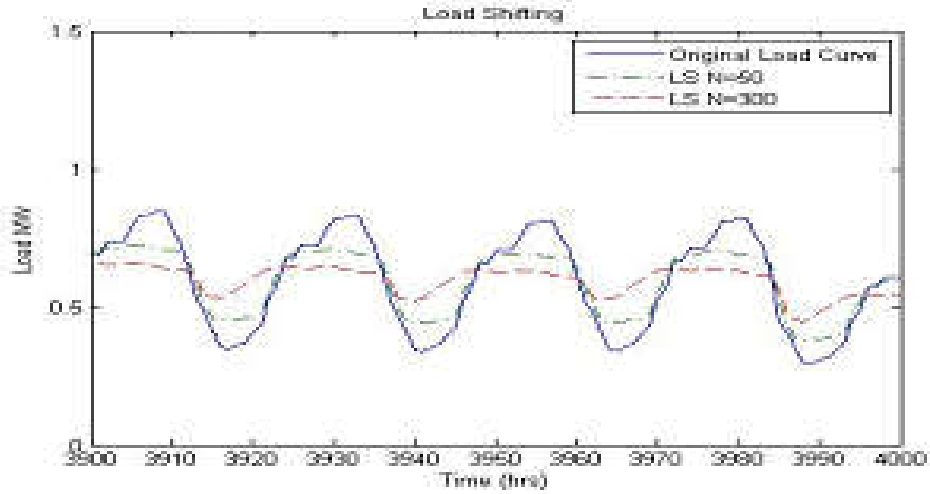

Fig. 3. Example of load shifting method

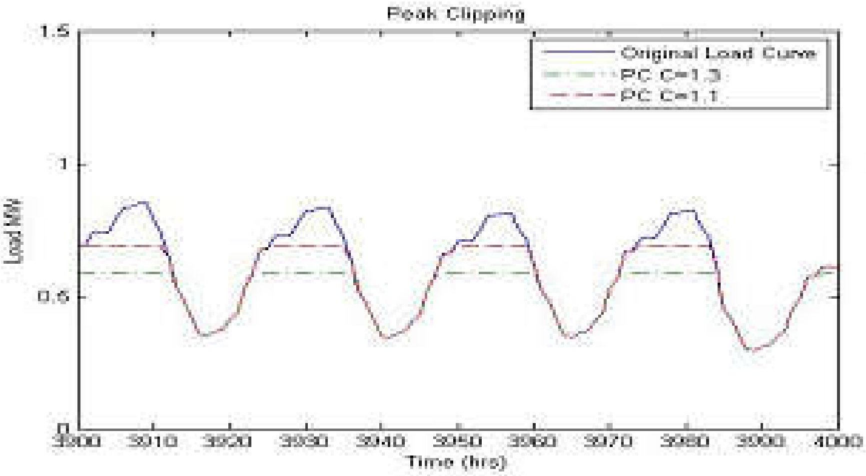

Fig. 4. Example of peak clipping method

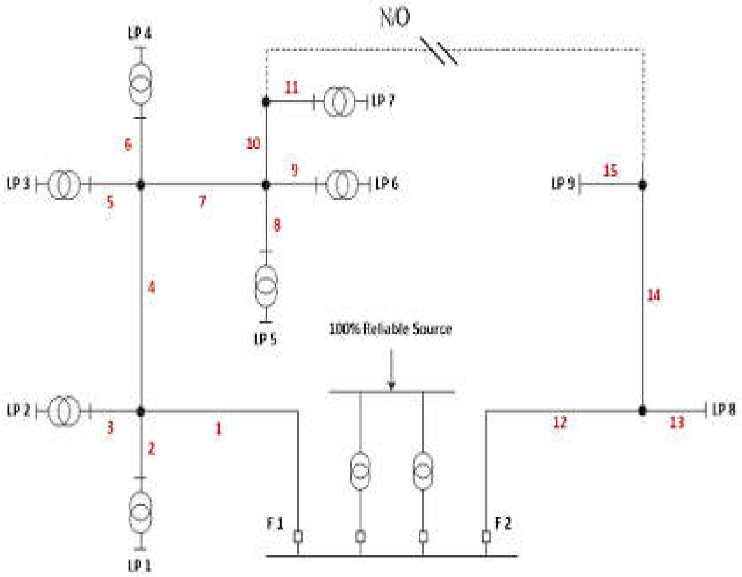

Fig. 5. RBTS-BUS 2 distribution system

Table I. Load points data

Load Point	Type	Average Load (MW)	No. Customers /LP
1-3	Residential	0.535	210
4,5	Cov/Inst	0.566	1
6,7	Commercial	0.454	10
8	Small user	1	1
9	Small user	1.15	1

A. Case Studies

Two fault cases are simulated and their locations are shown in Fig. 6. These are:
Case I: Fault at Branch 1

Case II: Fault at Branch 12

In both incident cases, the failure duration was assumed to be 5 hours based on the mean time to repair (MTTR) value of the faulted branches (10). The time to fail was specified using the inverse transform method. The established chronological hourly load model provides the peak loads at the simulated interruption hours for each point. After disconnecting one of the branches, the possibility of load restoration is assessed by solving the load flow problem of the RBTS system. The reliability of the grid will be further studied by connecting RE with different sizes as percentages of the total connected load peak in order to examine their effect on the restoration process. The power outputs for the solar panels and the wind turbine at failure time are extracted from their simulated hourly output data. Fig. 7 shows the connection location of the hybrid renewable system. After that, the system is re-assessed by applying LM techniques on the residential, governmental, and commercial customers of the network. Two LM methods are applied, which are load shifting and peak clipping. The load shifting and peak clipping factors are varied to measure their effect on load restoration. The system will be analyzed after applying different renewable resource integration and load management improvements. Table II summarizes the different sizes of wind turbines and PVs in the hybrid system, and the LM factors that will be studied. Note that the wind turbine and the PVs are connected simultaneously, while load shifting and peak clipping are applied separately. Also note that the last sizes of the hybrid system shown in Table II will be used only for the second case since greater generation will be needed due to faults occurring near high demand load points (LP 8 and LP 9).

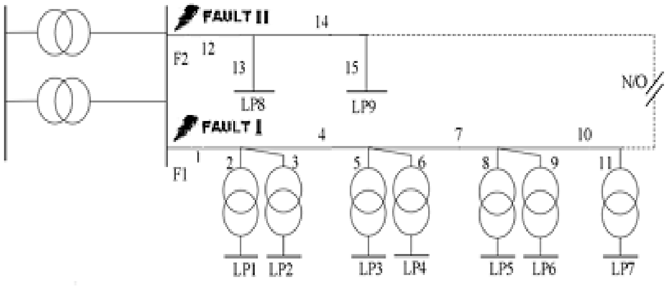

Fig. 6. Faults locations

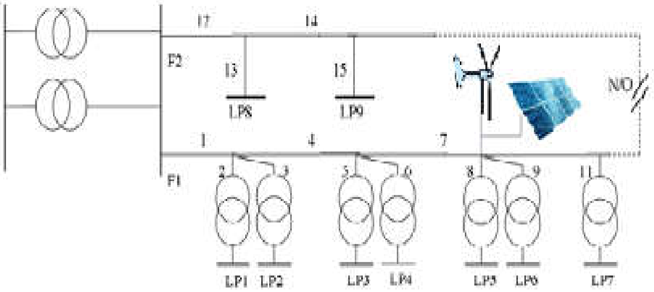

Fig. 7. Hybrid renewable system location

Table II. Different specifications for pv/wt sizes and lm factors

Hybrid Sizes (%of total load peak)		Load Management Shifting/Clipping	
WT	PV	LS factors	PC factors
Size1 1%	0.6%	N=100	C=1.3
Size2 2%	1.25%	N=200	C=1.2
Size3 3%	1.9%	N=300	C=1.1
Size4 4%	2.5%		

B. Results and Analysis

Two main case incidents are presented in this paper. Different scenarios were applied to improve the system restoration for each case as illustrated in Table II. The scenarios were compared based on SAIFI, SAIDI, ENS, and the interrupted loads with their average voltage levels. In total, 10 scenarios for each main case were studied, with changes in the hybrid system size, load shifting with different N shift factors, and peak clipping with different C clipping factors. Finally, for each case, two extra scenarios were analyzed in which hybrid renewable system and LM were both integrated into the system.

1) Case I: Failure at Branch 1

Considering the failure of Branch 1, load flow analysis was performed to calculate the voltage level for all loads. As discussed above, loads with a voltage level below 0.95 p.u. were considered lost or disconnected while loads with voltage within the limits were restored. Table III lists interrupted load points and their average voltage levels for case I. Table IV shows the reliability indices for scenarios with lost loads.

Table III. Case I restoration results

Scenario		Interrupted LPs	Lost LP Voltage Avg.
	Base	L1-6	0.9434
Hybrid	**Size 1**	L1-4	0.9464
	Size 2	None	-
	Size 3	None	-
LS	**N=100**	L1- 2	0.9493
	N=200	None	-
	N=300	None	-
PC	**C=1.3**	L1-2	0.9492
	C=1.2	None	-
	C=1.1	None	-

Table IV. Case I reliability indices

Scenario	SIAFI	SAIDI (hrs)	ENS (MWh)
Base	0.981	4.9	23.531
Size 1	0.965	4.8	15.6676
LS-N=100	0.642	3.21	6.5202
PC-C=1.3	0.642	3.21	6.9092

Table V. Combining re and lm – Case I

Scenario	Lost LP
Size 1 + LS (N=100)	None
Size 1 + PC (C=1.3)	None

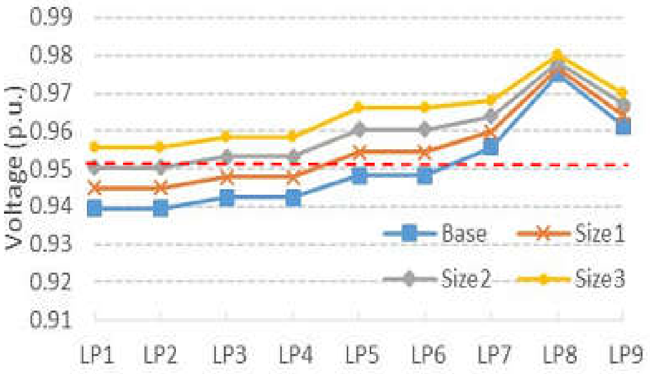

Fig. 8. Load voltage profile with different hybrid system sizes

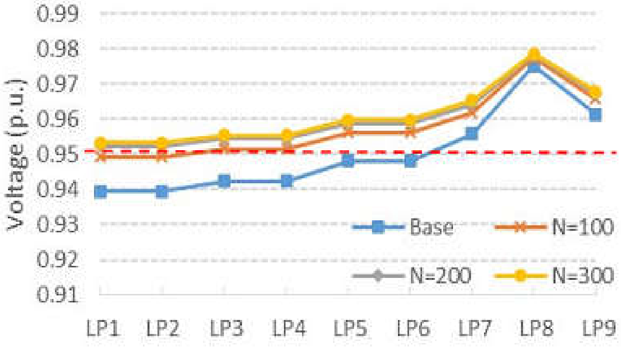

Fig. 9. Load voltage profile interchanging load shifting factor

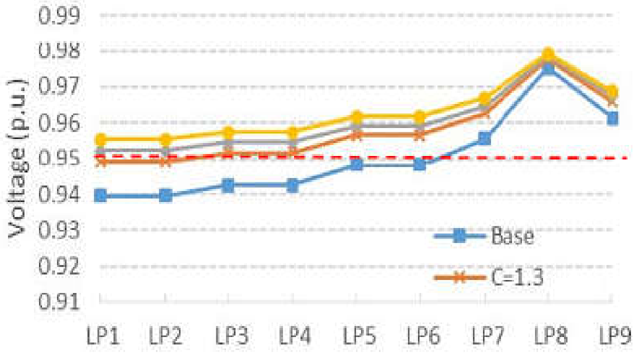

Fig. 10. Load voltage profile interchanging peak clipping factor

Table VI. Case II restoration results

Scenario		Interrupted LP	Lost LP Voltage Avg.
	Base	L5-L9	0.93504
Hyb.	Size 2	L7-L9	0.9379
	Size 3	N8,L9	0.93865
	Size 4	L8,L9	0.94335
LS	N=100	L7-L9	0.9334
	N=200	L7-L9	0.93567
	N=300	L7-L9	0.93693
PC	C=1.3	L7-L9	0.93483
	C=1.2	L7-L9	0.9365
	C=1.1	L7-L9	0.93823

Table VII. Case II reliability indices

Scenario	SIAFI	SAIDI (hrs)	ENS (MWh)
Base	0.0352	0.176	29.1435
Size 2	0.0183	0.0915	21.28
Size 3	0.003	0.015	17.5
Size 4	0.003	0.015	17.5
N=100	0.0183	0.0915	20.7101
N=200	0.0183	0.0915	20.2559
N=300	0.0183	0.0915	19.9252
C=1.3	0.0183	0.0915	20.151
C=1.2	0.0183	0.0915	19.9471
C=1.1	0.0183	0.0915	19.7432

Table VIII. Combining RE and LM – case II

Scenario	Lost LP
Size 4 + LS (N=300)	None
Size 4 + PC (C=1.1)	None

It can be noted in Table IV that SAIFI and SAIDI are highly affected due to a high number of customers connected near the fault location. Two extra scenarios were examined by combining renewable energy and LM for residential, governmental/institutional and commercial loads. This resulted in the complete recovery and restoration of all loads. Table V indicates the results after combining the scenarios with lost loads. In order to observe RE and LM effects more clearly, Figs. 8-10 show the voltage profile curves for all loads at each scenario for incident case I. In Fig. 8, the voltages are shown for each size of the hybrid system. In Figs. 9 and 10, the voltages are shown for each LS/ PC factor. The dashed line represents the minimum permissible voltage (0.95 p.u.).

1) Case II: Failure at Branch 12

In this incident case, Branch 12 is the one experiencing an outage. Tables VI and VII show the results. It can be noted that SAIDI and SAIFI are less affected now because the faults occurred near the small users where they account for only 0.3% of total customers. None of the scenarios completely restored all load points, but this can be achieved by combining RE and LM, as shown in Table VIII. It can be seen clearly that connecting hybrid renewable energy and applying LM can produce a significant effect in the voltage load profile and improve the load restoration process. Furthermore, when combining these two techniques, restoration of all loads can be achieved easily and more effectively.

IV. Conclusion

In this paper, the impact of LM and the integration of renewable energy on the restoration process was studied. Two faults on two different locations of the RBTS-BUS2 distribution system were simulated. Several scenarios were analyzed by connecting different hybrid system sizes and by interchanging the LM factors. SAIFI, SAIDI and ENS indices of the system were obtained at each incident case. The voltage profiles were also examined in order to test system restoration capability. It was realized that the integration of a wind turbine and solar panels to the system can largely improve the restoration process during an interruption. Furthermore, applying LM techniques on connected customers can also affect the reliability and system restoration.

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