Mansoura Engineering Journal

Volume 9 | Issue 2 Article 3

2-17-2022

Impacts of Introducing PV Power System into Different Distribution System Configurations on their Reliability.

M. H. El-Maghraby
Associate Professor, IEEE Senior Member, Faculty of Engineering, El-Mansoura University, Egypt.

S. A. Hassan
Vice Dean of Faculty of Engineering, El-Menoufia University, Egypt.

A. A. El-Zeftawy
Assist. Lecturer, Faculty of Eng. El-Menoufia Univ. Egypt.

Recommended Citation

H. El-Maghraby, M.; A. Hassan, S.; and A. El-Zeftawy, A. (2022) "Impacts of Introducing PV Power System into Different Distribution System Configurations on their Reliability.," *Mansoura Engineering Journal*: Vol. 9 : Iss. 2 , Article 3.
Available at: https://doi.org/10.21608/bfemu.2022.220151

IMPACTS OF INTRODUCING PV POWER SYSTEM INTO DIFFERENT DISTRIBUTION SYSTEM CONFIGURATIONS ON THEIR RELIABILITY

M.H. El-Maghraby, Associate Prof. IEEE Senior Member, Faculty of Eng., El-Mansoura Univ. EGYPT.

S.A. Hassan and Vice Dean of Faculty of Eng. El-Menoufia Univ. EGYPT.

A.A. El-Zeftawy Assit. Lecturer, Faculty of Eng. El-Menoufia Univ. EGYPT

ABSTRACT:

In the paper published by Milon, J.W., Capehart, B.L. and Kiker, C.F., mentioned in general words that a distribution system integrated with dispersed solar systems could improve the customer service reliability. But, they did't explain in detail how this can be attained and affected? [1]. So in our paper, this question is answered with full argument.

In the light of the compatibility of the meteorological conditions of EGYPT, the photovoltaic power systems are considered for the application. It is the demonstration to explain how this intermittent power supply can affect the distribution system reliability and its indices. The PV power system reliability-related factors are researched and analyzed. The location of integrating this system with the distribution one, its penetration level and the distribution system configurations are the most significant ones to be focused on.

The grade of the distribution system components from the effect of its reliability on that of the end-user service point of view is assigned. This is accomplished by carrying out a complete sensitivity analysis.

So, the planner and operator can consider the illustrated results out of this work into account throughout the execution of their tasks.

1. INTRODUCTION:

Reliability can be viewed as the probability that the supply is adequate to meet the load. Both elements, supply and load must be analyzed to develop a full understanding of reliability.

The distribution system can be made more reliable by increasing the level of component redundancy and the reliability of individual component, by increasing the quantity and quality of maintenance, by structuring the distribution system to allow greater flexibility. The problem is that all of these actions increase the cost. The real problem then is to strike the proper balance between service reliability and its cost.

The reliability of an intermittent power system (IPS) depends, generally, on their availability, the forced outage rate of the units and their maintenance requirements. Consequently, their intermittance is the demonant factor influencing the reliability of a distribution system integrated with such sources. Its variable nature makes some hours subject to capacity shortage, thus hourly load data will be necessary for all hours of the day to perform the reliability analysis.

Moreover, since load and the various intermittent resources tend to vary with season, the seasonal correlation between IPS output and load is significant in determining whether or not the intermittent capacity is sufficient to meet the load. It will probably be sufficient to examine this effect on monthly basis [2] . One approach to solving the problem of the relatively low availability of IPS plants is to complement them with energy storage devices [3] .

In the present paper, the photovoltaic (PV) power system is taken as an intermittent power system for research in the light of its compatibility for the meterological conditions of EGYPT. Its output fluctuates according to the insolation and load demand levels at any instant [4] . Its reliability is influenced by several factors [3] :

1. Solar plant penetration.
2. Storage usage.
3. Forced outage rate.
4. Scheduled outage.
5. Amount of insolation.
6. Insolation correlation with load.
7. Correlation of insolation outage between plants installed at different sites.

So, the principal aim of this work is to deal with the impacts affecting the reliability of distribution system of various configurations integrated with the PV power system. Location of PV power system with respect to distribution system and its penetration levels are the salient ones. A complete sensitivity analysis is accomplished to find the effect of a decremental change of the conventional supply, distribution system components and PV system reliability on the distribution and whole systems reliability. Moreover, the effect of series-parallel connections of SCA modules and their tilt angle on the PV power system reliability and consequently on that of the distribution and whole systems are investigated.

NOMENCLATURE:

CPS	: Conventional power system.
PVPS	: Photovoltaic power system.
PC	: Power conditioner.
F_n	: Feeder number, n = 1,2,...
DT	: Distribution transformer.
SCA	: Solar cells array.
TL_{PV}	: Penetration level of PV power system, %
C	: Battery storage capacity, MWh/month.
$\bar{I}$	: Average interruption frequency index.
d	: Average interruption duration index.
CRI	: Cost reliability index.
R_i	: Reliability level of ith distribution component, p.u.
ΔR_i	: Decremental change in R_i, %
R_{DS}	: Reliability level of the distribution system, p.u.
R_{WS}	: Reliability level of the whole system, p.u.
ΔR_{DS}	: Percentage change in R_{DS}.
ΔR_{WS}	: Percentage change in R_{WS}.
R_A	: Substation reliability, p.u.
R_B	: Main feeder reliability, p.u.
R_C	: High voltage breaker (HB) connector reliability, p.u.
R_D	: Distribution transformer reliability, p.u.
R_E	: Low voltage breaker (LB) connector reliability, p.u.
R_F	: Low voltage bus reliability, p.u.
R_{PV}	: PV power system reliability, p.u.
R_T	: Generation and transmission reliability, p.u.
S - P	: Series-parallel modules connection.
C_{ci}	: Per unit number of conventional supply-fed customers affected by the faulted ith component.
X_{ci}	: Circuit miles or number of units fed by conventional supply.
λ_{ci}	: Failure rate of ith component fed by conventional supply.
C_{PVk}	: per unit number of PV system-fed customers affected by the faulted kth component, it is numerically equal to TL_{PV}.
X_{PVk}	: Number of units fed by PV system.
λ_{PVk}	: Failure rate of the kth component fed by PV system.
C_{cij}	: Per unit number of conventional fed-customers, affected during step by step operation of work function (j: index for work function).
t_{cij}	: Time required in step by step operation of work functions for conventional fed-customers.
C_{PVkl}	: Per unit number of PV system fed-customers affected during step by step operation of work function (l: index for work function).
t_{PVkl}	: Time required in step by step operation of work functions for PV fed-customers.
c	: System cost per customer.

2. MODELLING OF RELIABILITY:

In this section, the aim is to construct generalized models to assess the reliability of a photovoltaic, distribution and whole systems. The whole system incorporates the conventional generation, transmission and the distribution subsystems integrated with the PV power system. The reliability assessment is carried out on introducing the PV power system into the distribution system positioned at different locations explained in Fig. 1. The photovoltaic power system is centrally-located if it is integrated with the substation (Fig. 1-a). This intermittent system may also be introduced into the electrical distribution system at the bus-bar of the distribution transformer (DT) as seen in Fig. 1-b. The third location considered, here, is to supply a percentage of the load demand directly by the PV power system, on-site alternative, Fig. 1-c.

The models of the distribution system reliability are developed by knowing that of its components and of the PV power system. The following subsections will describe the methodology of computing these reliability levels.

2.1. PV Power System:

By the aid of the approach published in reference [5], the loss-of-load probability (LOLP) and the PV power system reliability (R_{PV}) are estimated. Here, this methodology is carried out for all the year months. This reliability which has a Poisson method is influenced by the insolation of the site considered, the reliability of each PV system components, the load demand and the battery storage capacity [5,6].

The reliability of the main component of PV power system, solar cells array, is governed by its series - parallel modules connections and its tilt angle [4] . So, the reliability of PV power system is estimated for these conditions and introducing it into the general models of distribution system reliability. Widespread application is accomplished to illustrate their impact.

2.2. Electrical Distribution System:

2.2.1. Reliability indices:

The distribution system reliability indices of prime concern that will be examined here are: the average interruption frequency index ($\bar{f}$), average interruption duration index ($\bar{d}$), and cost reliability index (CRI) [7]. They are modified for the system integrated with the PV power supply due to the following considerations:

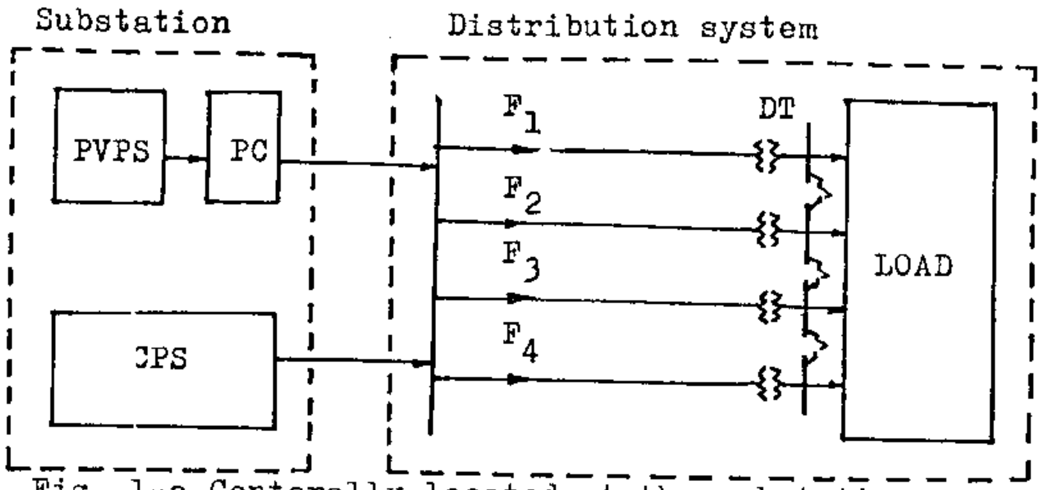


Fig. 1-a Centerally-located at the substation bus bar

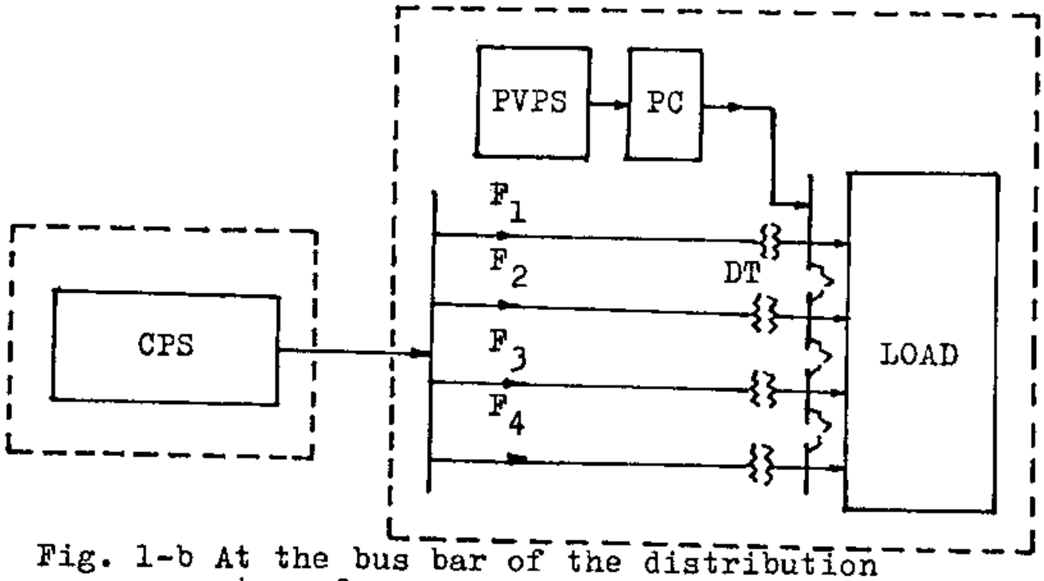


Fig. 1-b At the bus bar of the distribution transformer.

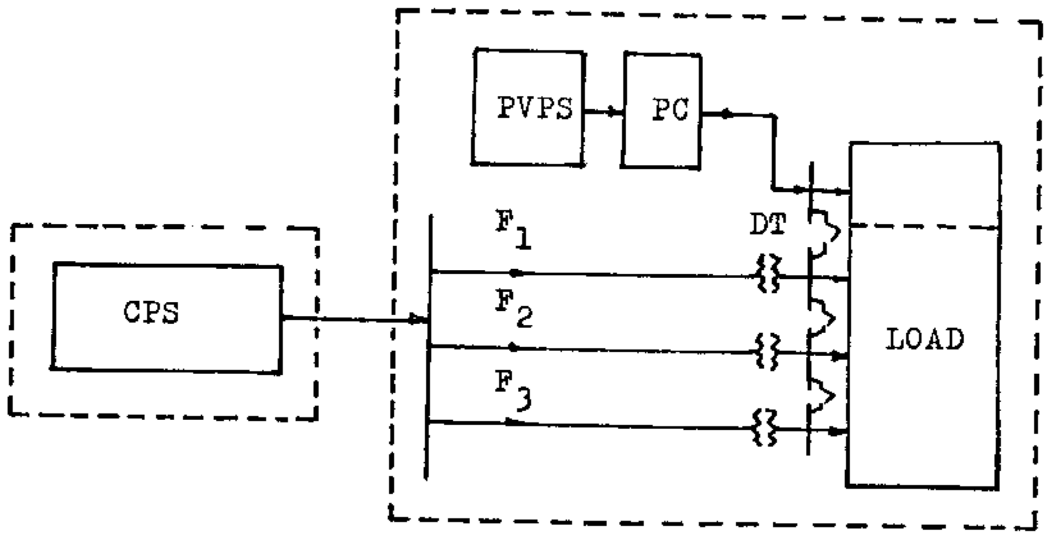


Fig. 1-c On-site location.

Fig. 1 Locations studied of photovoltaic power system introduced into the distribution system.

1. The independency of PV power system out of the conventional supply due to the difference of their nature.
2. Certain number of customers will be fed by an appropriate penetration level of PV power system. Its per unit value referred to the total number of customers is equal, numerically, to this level.

So, the modified reliability indices are developed having the following forms:

$$\bar{f} = \sum_i c_{ci}\, x_{ci}\, \lambda_{ci} + \sum_k c_{PVk}\, x_{PVk}\, \lambda_{PVk} \quad \ldots.(1)$$

$$\bar{d} = \sum_i x_{ci}\, \lambda_{ci}\, (\sum_i c_{cij}\, t_{cij}) + \sum_i x_{PVk}\, \lambda_{PVk}\, (\sum_l c_{PVkl}\, l_{PVkl}) \quad \ldots..(2)$$

$$CRI = \frac{1}{c.\bar{d}} \quad \ldots..(3)$$

2.2.2. Reliability level:

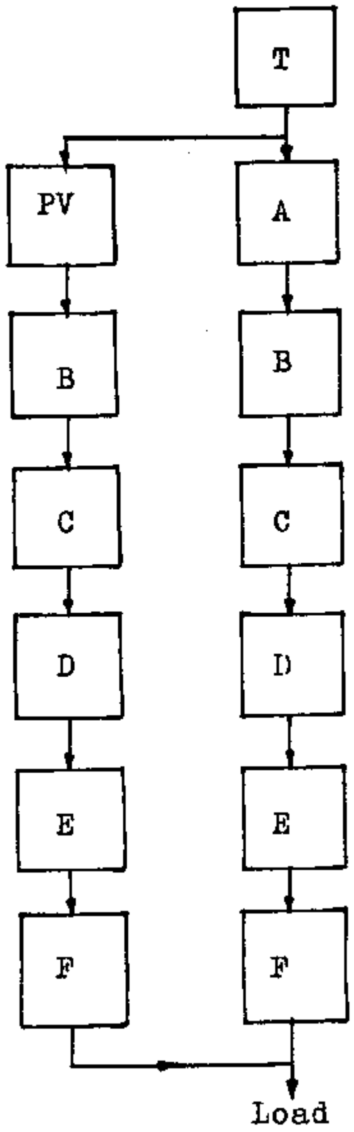
On introducing the PV power system into an electrical distribution system, the reliability of the latter is deduced dependent on the reliability of each component. Its components are displayed in Fig. 2. Their reliability levels are derived knowing the failure rate data and the interruption duration time [7] . Various distribution system configurations shown in Fig. 3 are taken for research.

The estimation of the whole system reliability can be easily attained by introducing the reliability levels of the conventional generation and transmission subsystems into the general reliability models.

From reliability block diagrams illustrated in Fig. 2, for any of the distribution system configurations, mathematical models can be determined resulting in the following forms:

a) Centrally-located:

$$R_{DS} = 1 -(1 - R_A R_B R_C R_D R_E R_F)(1 - R_{PV} R_B R_C R_D R_E R_F) \quad \ldots..(4)$$



T Generation and transmission
A Substation
B Main Feeder
C HB connector
D Distribution transformer
E LB connector
F Low voltage bus
PV PV system.

Fig. 2-a Centrally-located at the substation bus-bar.

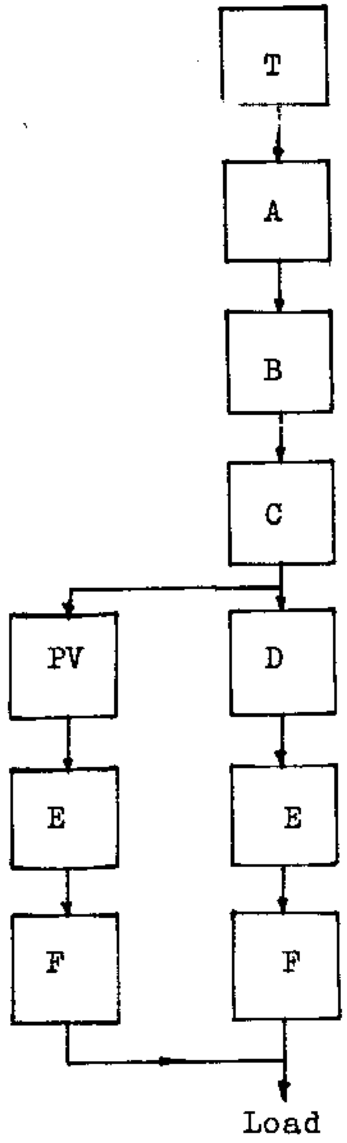


Fig. 2-b At the bus-bar of distribution transformer.

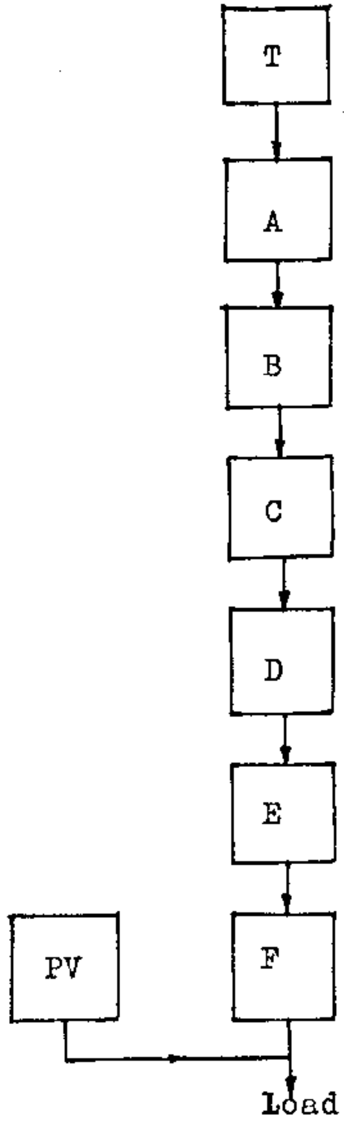


Fig. 2-c On-site Location

Fig. 2 Reliability block diagram of PV power system integrated with CPS at different locations on the distribution system.

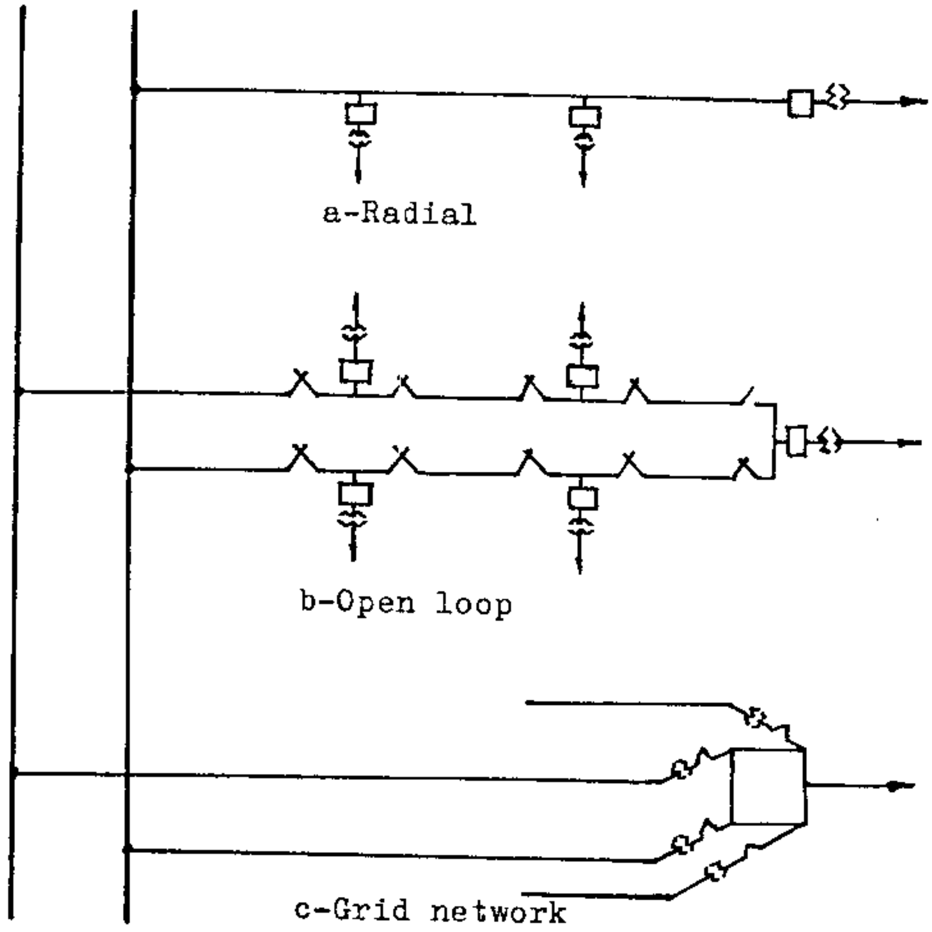


Fig. 3 Major distribution system configurations taken, here, for studied.

$$R_{WS} = \left[1-(1 - R_A R_B R_C R_D R_E R_F)(1- R_{PV} R_B R_C R_D R_E R_F)\right] R_T \quad ..(5)$$

b) At the bus-bar of DT location:

$$R_{DS}=\left[1- (1- R_D R_E R_F)(1 - R_{PV} R_E R_F)\right] R_A R_B R_C \quad .....(6)$$

$$R_{WS}=\left[1- (1- R_D R_E R_F)(1 - R_{PV} R_E R_F)\right] R_A R_B R_C R_T \quad .....(7)$$

c) On-site location:

$$R_{DS} = 1- (1 - R_A R_B R_C R_D R_E R_F)(1 - R_{PV}) \quad .....(8)$$

$$R_{WS} = 1- (1 - R_T R_A R_B R_C R_D R_E R_F)(1 - R_{PV}) \quad .....(9)$$

The effect of distribution system configurations on its reliability will be sensible due to the variation of interruption time of components constituting their different branches.

3. SENSITIVITY ANALYSIS:

These analyses are carried out to find the effect of change in the reliability of the conventional power supply and the distribution components on that of the distribution and whole systems using the previous models (4) - (9). The importance of this issue is to explore and assign the most significant component of the power system that affects its reliability. Also, it is aimed at finding the best solution to control the reliability at the consumers within rational values.

These analyses are carried out under the effect of the following assumptions:

1. Constant and nominal penetration level of PV power system is considered (5% is taken here as a pertinent figure). So, the corresponding reliability of the distribution and whole systems is taken as a reference value for comparison.
2. The change in the reliability of distribution and whole systems is estimated with a decremental change in that of one component only keeping those of others being constant. i.e., individual effect of each component reliability will be illustrated.
3. Influence of the site of installing the PV power system has been investigated beside the above analysis.

4. Practical and wide range of the decremental changes in the components reliability is explored to accomplish these analyses.
5. Open-loop distribution system is the configuration taken for these analyses.

4. ROLE OF BATTERY STORAGE:

Due to the nature of intermittance of intermittent power sources and their fluctuation in output, the reliability control is necessary to have its required level at all operational conditions. As stated, the new reliability level of the distribution system depends primarily upon the change in the reliability of supply and distribution components. The control of reliability of the supply with its categories (conventional or intermittent) is more easier, than for the distribution components with the same load profile. The control of conventional supply reliability depends on the planning outage and the spinning reserve power. On other hand, the control of intermittent power system reliability can be accomplished by the aid of an energy storage. This storage which is oftenly a battery, can be charged from a conventional or an intermittent power source [2] . For the PV power system, the amount of storage capacity needed depends upon the available output power, penetration level, and the required level of reliability. The significant factors affecting this issue is the monthly average daily insolation at a specific load in addition to the total life-cycle costs of the PV power system involving battery storage. So, the reliability/ cost trade-off must be analyzed and discussed.

5. CASE STUDY:

As a case study, Menouf site (30° 8' N) with its electrical distribution system is taken as a specific problem to apply the aforementioned approach. Full specifications were previously mentioned in a paper of the authors which stated in the appendix (A) [8].

On solving this problem, the prementioned models are applied with the following assumptions:

1- Summar and winter daily load curves are used.
2- Pre-determined global size of solar cells array is used [8] .
3- Usage of a battery storage with the PV power system to meet its penetration levels.
4- Generation and transmission subsystems reliability is assumed to have a level of 0.99.
5- The distribution components have the same failure rate independent of its configurations.

5.1. Assessment of PV Power System Reliability:

5.1.1. Estimation of monthly battery storage capacity:

To achieve a certain penetration level 5%, say, the subglobal optimum solar cells array sizes are computed for the year months with the same methodology stated in the previous paper of the authors [8] . Thus, the corresponding global optimum SCA size can be derived for Menouf site. Due to the variation in insolation received monthly, a need is substantial for a pertinent capacity of a battery storage to achieve the aforementioned penetration level. This capacity varies monthly as depicted in Fig. 4. So, the assessment of the loss-of-load probability (LOLP) and reliability level (R_{PV}) of the PV power system have thus been found monthly. This system incorporates its heart, solar cells array, power conditioner, blocking diode, switches, relays and connections, and battary storage. Fig. 5 reveals the behaviour of LOLP and R_{PV} against the year months.

An average value of R_{PV} is deduced out of their towelve levels and introducing it into the calculation process of distribution system reliability.

Although the enhancement of the battery storage capacity increases the reliability of PV power system, this will not strongly improve that of the distribution system integrated with it as an intermittent power supply. Logically, this addition of battery capacity increases the total life-cycle costs of the PV power system.

5.1.2. Effect of series-parallel modules connection on R_{PV} and R_{DS}:

Since the solar cells array (SCA) is the main element of the PV power system, its reliability (R_a) affects pronouncely that of the PV power system. From previous literature, the series-parallel modules strongly influences R_a [4, 9] .

With PV power system integrated with a distribution system, it is the purpose, here, at finding the effect of the method of internal connection of SCA modules on R_{DS}. So, five methods of series-parallel connection of SCA modules are suggested and investigated to estimate the corresponding R_a, R_{PV} and R_{DS}. These methods are:

The first, S-P1 : The array consists of 2 blocks each of 108 parallel strings which includes 6 series modules.

The second, S-P2 : The array consists of 3 blocks each of 108 parallel strings which incorporates 4 series modules.

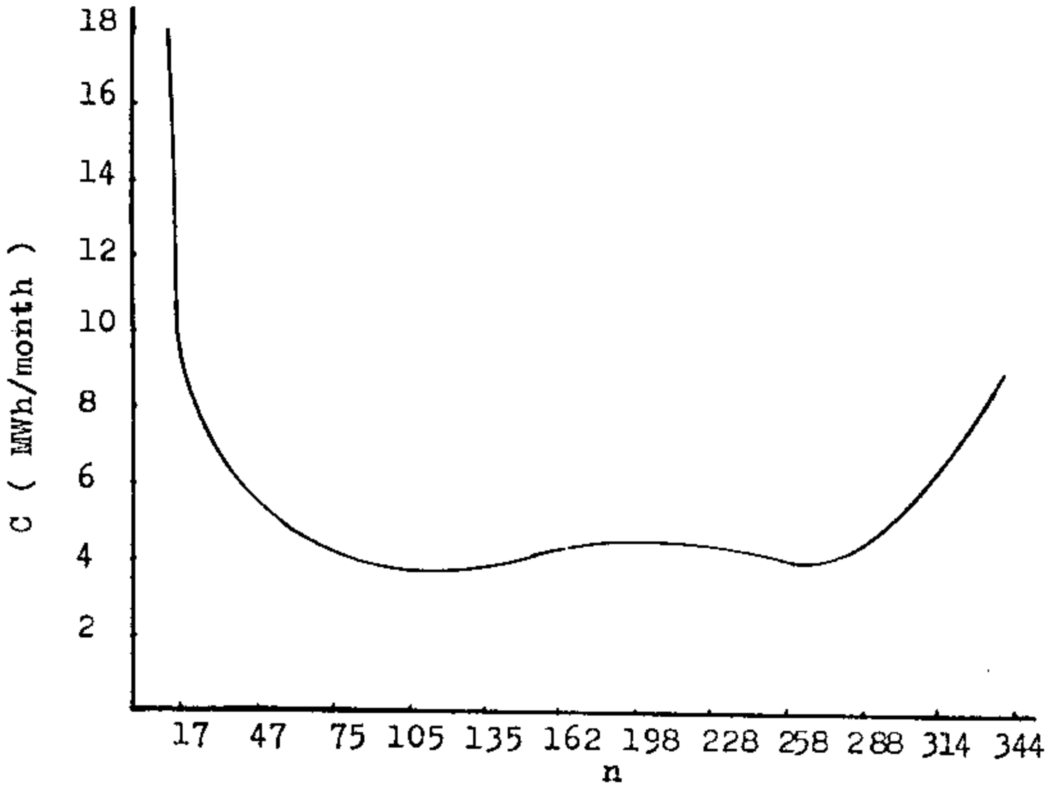


Fig. 4 Storage capacity needed for different year months to complement the PV power system output with a 5% penetration level.

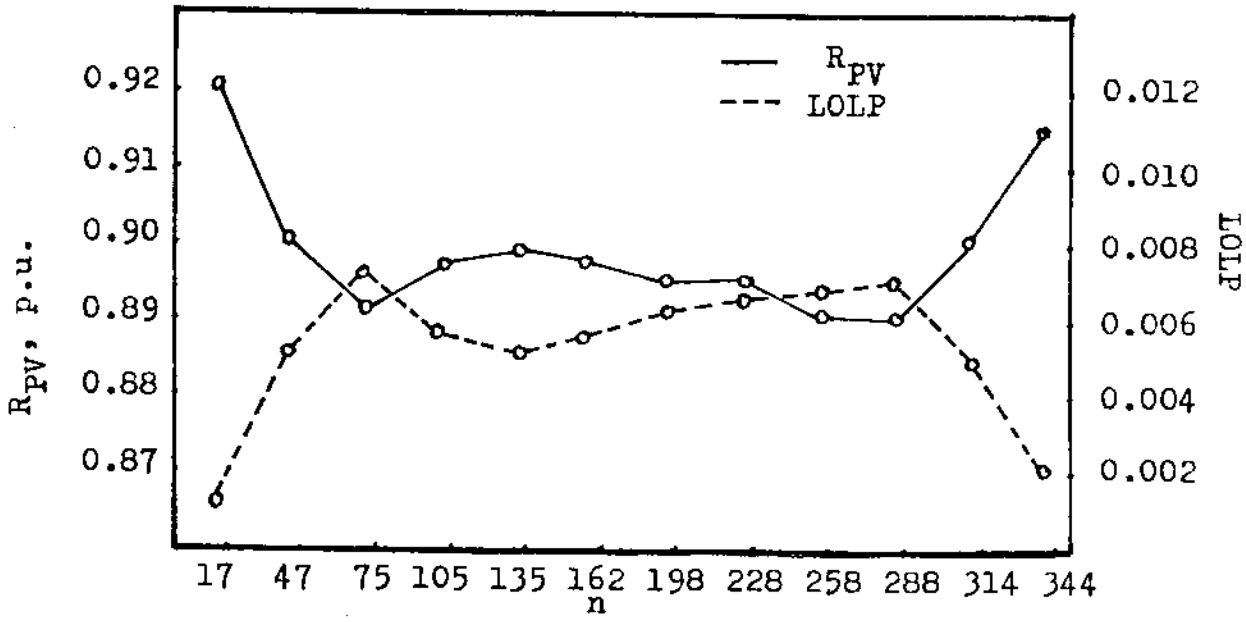


Fig. 5 Reliability index and level of PV power system at different year months with a 5% penetration level

The third, S-P3: The array consists of 4 blocks each of 108 parallel strings which involves 3 series modules.

The fourth, S-P4: The array consists of 6 blocks each of 108 parallel strings which involves 2 series modules.

The fifth, S-P5: The array consists of 12 blocks each of 108 parallel strings which incorporates only single module.

The results are plotted in Fig. 6. Out of which, it is shown that in spite of strong response of R_{PV} to the method of connection, the distribution system reliability has not been considerably affected. It has a flat characteristic. The figure also, displays the behaviour of whole system reliability against the method of connection.

5.1.3. Effect of SCA tilt angle on R_{PV} and R_{DS}:

In this subsection, the change of R_{PV} and R_{DS} as a result to the variation in SCA tilt angle is researched. So, several tilt angles are taken for a numerical application keeping the SCA global optimum size being constant. The results are drawn in Fig. 7. The same conclusion is obtained out of this investigation. i.e., there is a slight variation attained in R_{DS} on changing the SCA tilt angle.

So, the following general conclusion can be drawn out of the preceding three subsections. Any factor that can affect the reliability of the PV power system is not necessary to influence appreciably that of the distribution system integrated with the preceding intermittent power supply.

5.2. Distribution System Reliability:

5.2.1. Reliability indices:

The distribution system reliability indices are estimated by the application of the modified eqns. (1-3) prementioned in subsection 2.2.1. They are found by penetrating the PV supply with different levels and for discriminated configurations of distribution system illustrated in Fig. 3.

Due to the low figures of the failure rate of PV system components, an acceptable approximation is presumed as follows:

$$\sum_{k} c_{PVk} \; x_{PVk} \; \lambda_{PVk} = c_{PV} \; x_{PV} \; \lambda_{PV}$$

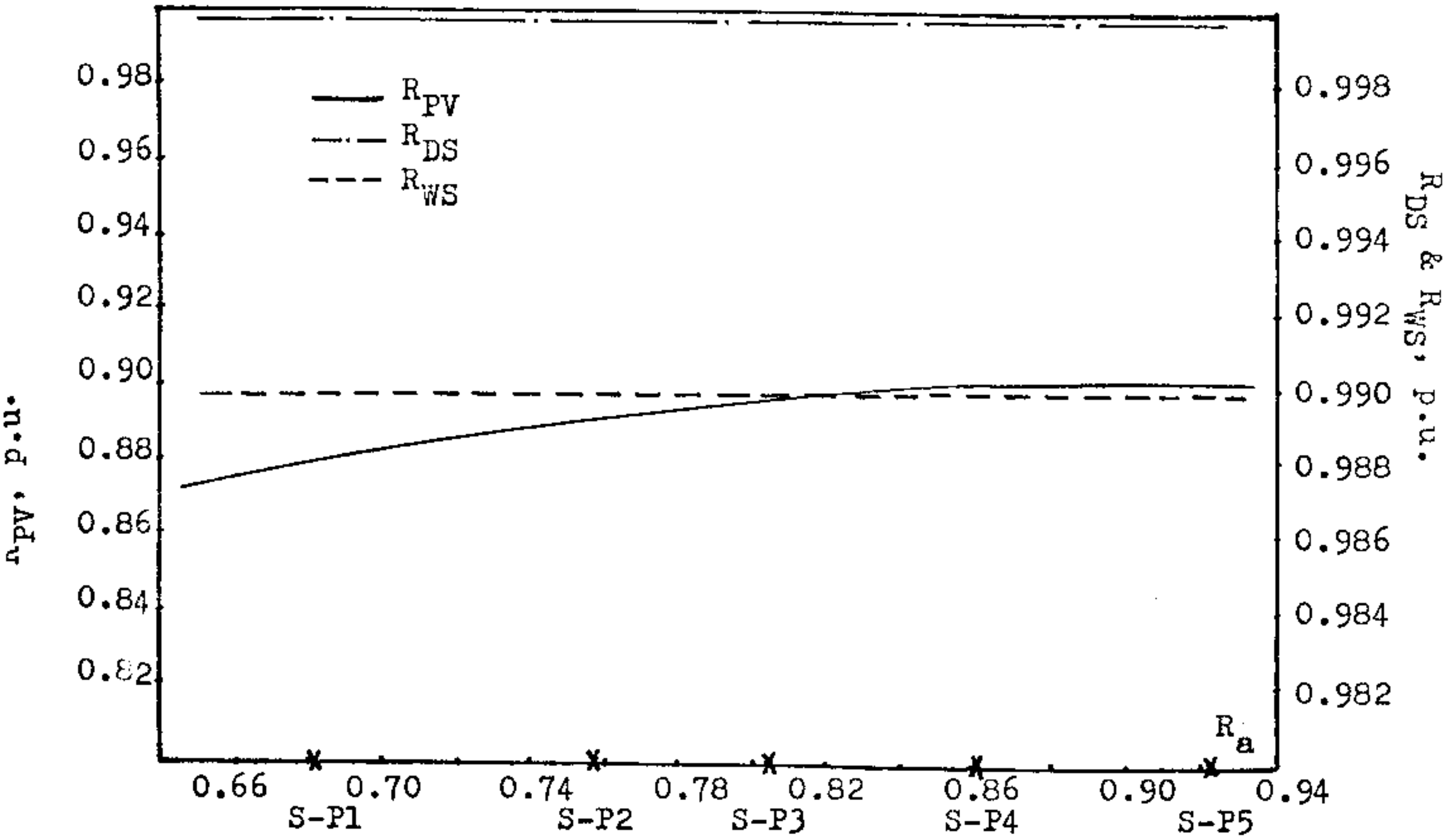


Fig. 6 Effect of series-parallel modules connection on R_a, R_{PV}, R_{DS} and R_{WS}.

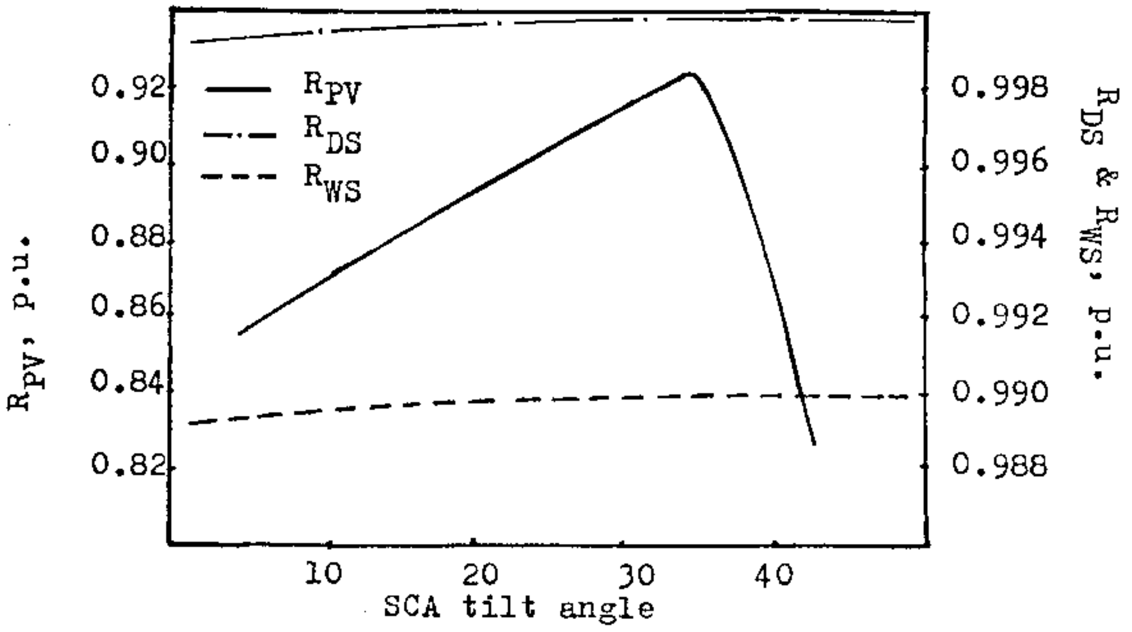


Fig. 7 Effect of SCA tilt angle on R_{PV}, R_{DS} and R_{WS}

This approximation depends on the assumption of having the PV system as one unit. Its failure rate is assumed to have the worst figure belonging to the solar cells array.

Table (1) summarizes these indices for the imposed conditions.

Considerable effect is noticed on powering different distribution system configurations. This can be ascribed due to the change of the interruption time of their components. On other hand, slight effect is noticed with various penetration levels of PV power system.

5.2.2. Reliability level:

By applying the mathematical models stated in section 2.2.2, the reliability of distribution and whole systems can be computed and tabulated with different penetration levels and locations of PV power system in Table (2) with open loop configuration.

This table demonstrates that the integration of PV power system with the distribution system, at the considered locations, improves its reliability. Moreover, the impacts of changing the PV penetration level have slight effect on R_{DS} and R_{WS}.

Exploring the effect of changing the distribution system configuration on its reliability, the problem is solved for prementioned ones. Table (3) tabulates the results on interconnecting the PV system with different penetration levels. As it is expected the highest reliability level is obtained for the grid network type. In addition, this interconnection improves the distribution system reliability for all configurations.

Table (3): Effect of introducing PV power system into distribution system with different configurations on its reliability level at centrally-located of PV system.

TL_{PV}, % / DS Configuration	0	5	20
Radial	0.99570	0.99955	0.99921
Open loop	0.99709	0.99967	0.99954
Grid network	0.99768	0.99976	0.99957

Table (1) Effect of introducing PV power system into distribution system with different configurations on its reliability indices.

Reliability indices / TL_{PV}, % / DS Configuration	$\bar{f}$			$\bar{d}$			CRI		
	0	5	20	0	5	20	0	5	20
Radial	0.6140	0.6136	0.6138	1.415	1.413	1.414	63.099	63.20	63.14
Open loop	0.3200	0.3190	0.3197	0.739	0.737	0.7382	112.80	113.10	112.90
Grid network	0.1820	0.1810	0.1814	0.401	0.399	0.4005	166.30	167.50	160.50

Table (2) The reliability level of the distribution and whole systems with different penetration levels and locations of the PV power system with open loop configuration.

Penetration Level (TL_{PV}), %	Centrally-located		Secondary Feeder location		On-site Location	
	R_{DS}	R_{WS}	R_{DS}	R_{WS}	R_{DS}	R_{WS}
0	0.99709	0.98703	0.99709	0.98703	0.99709	0.98703
5	0.99967	0.98969	0.99830	0.98832	0.99969	0.99872
10	0.99961	0.98961	0.99827	0.98828	0.99962	0.99869
20	0.99954	0.98953	0.98543	0.98825	0.99957	0.99854

5.3. Sensitivity Analyses:

Table (4) illustrates the results obtained by assuming a hypothetical decremental change of the component reliability (ΔR_i) and its impacts on the distribution system reliability. The followings are the important conclusions that can be drawn out of these analyses:

a) With certain location, increasing the decremental change, ΔR_i, results in a decrease in R_{DS} and R_{WS}. The amount of this decrease differs according to the component types and alternative locations of PV power system.

b) The on-site location is superior over other alternatives with the concern of the sensitivity of a change in R_{DS} due to certain decremental change of the distribution components reliability, e.g.

ΔR_i = 1% leads to ΔR_{DS} = 0.102%, and

ΔR_i = 10% leads to ΔR_{DS} = 1.038%.

except for PV power system which has the following figures.

ΔR_{PV} = 1% results in ΔR_{DS} = 0.0002%, and

ΔR_{PV} = 10% results in ΔR_{DS} = 0.0263%.

This conclusion can be attributed owing to the fact of having a quite different reliability block diagrams than other locations. The latters display that, in contrast to the on-site location, all or sum of the distribution components with the PV power system except the substation are arranged in parallel to the conventional supply path. This will, consequently, affect the corresponding models as previously explained.

c) Following the on-site location is the centrally-located PV power system where:

ΔR_i = 1% leads to ΔR_{DS} = 0.115%, and
ΔR_i = 10% leads to ΔR_{DS} = 1.098%.

These figures are not correct for PV power system, i.e.

ΔR_{PV} = 1% leads to ΔR_{DS} = 0.0008%, and

ΔR_{PV} = 10% leads to ΔR_{DS} = 0.027%.

d) Regarding the secondary feeder location, there are appreciable changes in R_{DS} corresponding to the same prementioned ΔR_i. This can be ascribed to the fact to having three series components in the reliability block diagram: substation, main feeder and high voltage breaker connector before the point of injecting PV power. This is not the case for other locations.

Table (4) Effect of decremental change in components reliability on that of distribution and whole systems at different PV power system locations and 5% penetration level

(1) Centrally-located

Decremental change in R_i (ΔR_i), %	1		2		3		10	
Component	R_{DS} %	R_{WS} %	R_{DS} %	R_{WS} %	R_{DS} %	R_{WS} %	R_{DS} %	R_{WS} %
Generation & Transmission	--	0.9996	--	1.999	--	2.999	--	9.860
Substation	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
Main Feeder	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
High Voltage breaker connector	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
Distribution Transformer	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
Low voltage breaker connector	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
Low voltage bus	0.115	0.114	0.229	0.227	0.344	0.341	1.098	1.096
PV power system	0.0008	0.0005	0.004	0.003	0.007	0.006	0.027	0.027

(2) Secondary Feeder Location

Generation & Transmission	--	0.988	--	1.998	--	2.996	--	9.982
Substation	0.988	0.979	1.986	1.968	2.985	2.957	9.985	9.885
Main Feeder	0.988	0.980	1.987	1.969	2.986	2.958	9.990	9.889
High Voltage breaker connector	0.988	0.980	1.987	1.969	2.986	2.958	9.990	9.799
Distribution Transformer	0.104	0.102	0.208	0.206	0.313	0.310	1.045	1.034
Low voltage breaker connector	0.114	0.112	0.246	0.243	0.396	0.392	1.095	1.093
Low voltage bus	0.114	0.112	0.246	0.243	0.396	0.392	1.095	1.093
PV power system	0.0005	0.0002	0.0014	0.0007	0.0023	0.0016	0.009	0.0078

(3) On-site location

Generation & Transmission	--	0.093	--	0.197	--	0.301	--	1.029
Substation	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
Main Feeder	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
High Voltage breaker connector	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
Distribution transformer	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
Low Voltage breaker connector	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
Low voltage bus	0.102	0.092	0.206	0.195	0.310	0.298	1.038	1.019
PV power system	0.0002	0.0012	0.0031	0.0141	0.0060	0.0273	0.0263	0.117

It is aimed by carrying out these analyses at determining the component that the change of its reliability has a remarkable effect on that of the distribution system with different PV power system locations. So, the planner and the operator can consider the illustrated results, Table (4), into account throughout the execution of their tasks.

6. CONCLUSIONS:

Regarding the impacts of interconnecting PV power system as an intermittent supply with a distribution system, the following main conclusions drawn from this paper are obtained:

1- Salient factors that affect the reliability of the PV power system are not necessary to change appreciably that of the distribution system.

2- The distribution system reliability indices are dependent strongly on its configurations resulting in best ratios with grid network. However, they are slightly affected by the PV system penetration levels.

   The same behaviour is noticeable for the reliability levels.

3- The on-site location is superior over other alternatives with the concern of the sensitivity of a change in R_{DS} due to certain decremental change of the distribution components reliability.

An hypothetical decremental change in reliability of the series component in reliability block diagram results in the same decremental change in the distribution system reliability. Moreover, with the components constituting the parallel path of the foregoing diagram, the decremental change in the distribution system reliability has a value of 0.1 of that of the components.

These conclusions recommend the designer of a distribution system to encourage them to inject the PV power output into his conventional system.

REFERENCES:

[1] J. Walter Milon, Barney L. Capehart and Clyde F. Kiker, "Planning, Pricing and Public Policy Issues for Reliability of Interconnected Solar Energy Systems" IEEE Transactions on Reliability, Vol. R-31, No. 3, August 1982, pp. 308-312.

[2] System Control Inc., "The Effect of Distributed Power System on Customer Service Reliability" EPRI El-2549, Contract TPS 79-759, August 1982.

[3] Joh, T. Day and Walter J. Hobbs, "Reliability Impact of Solar Electric Generation Upon Electric Utility Systems" IEEE, Transactions on Reliability, Vol. R-31, No. 3, August 1982, pp. 304-307.

[4] D.L. Pulfrey, "Photovoltaic Power Generation", Book, Van Nostrand Reinhold Company, 1978.

[5] H.L. Macomber, J.B. Ruzek, F.A. Costello and Staff of Bird Engineering Research Associates, "Photovoltaic Stand-Alone System: Preliminary Engineering Design" Handbook prepared for NASA, Le RC, Contract DEN 3-195, August 1981.

[6] M.H. El-Magharby and H.H. El-Tamally, "Reliability Study of Solar Photovoltaic Power System" Proceeding of Fifth European Conference on Electrotechnics-EUROCON 82, Copenhagen, Denmark, June 14-18, 1982, pp. 859-863.

[7] N.E. Change, "Cost-Reliability Evaluation of Commercial and Industrial Underground Distribution System Design" IEEE PES Winter meeting, New York, NY, A 79 058-9, February 4-9, 1979.

[8] S.A. Hassan, M.H. El-Maghraby and A.A. El-Zeftawy, "Quantitative Analysis of Operational Impacts on Distribution System Integrated with Photovoltaic Power System" AMSE 1984 International Conference, Athens, June 27-29, 1984, Sec. 3-3.

[9] M.H. El-Maghraby, Y.A. Abde and M.A. El-Sayes, "Proposed Generalized model for estimating the reliability of a stand-alone solar photovoltaic power system" EPSR, Vol. 8, No. 2, March, 1985, pp. 111-118.

[10] Egyptian Ministry of Electricity and Energy, Personal Communication.

APPENDIX (A):

1. Distribution System Studied:

City	: Menouf, Egypt.
Configuration	: Open Ring
Working voltage, kV	: 11
Failure rate of distribution System components, and their interruption time	: Ref. [7, 10] .

2. Load Data 10 :

Particularies / Season	Peak Load kW	Load Duration (hrs)	Daily load Demand (kWh) Day time	Daily load Demand (kWh) Low-Ins. & night	Daily load Demand (kWh) Total	Load Power factor	Load Factor
Winter	3229	3	11426	30545	41971	0.8	0.54
Summer	3105	1	14900	31221	46121	0.8	0.62