Effect of maintenance on reliability of Microgrid

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***Abstract*—this article examines the impact of maintenance on reliability of microgrids. At first analysis of a system with two members has been accommodated and then it has been tested in a microgrid and it has been numerically analyzed. The effect of repairable elements or non-repairable elements has been evaluated in parameters MTTFF and MTTF.**

Keywords-Mean time to failure (MTTF); mean time to first failure (MTTFF); Microgrid; repair

I. INTRODUCTION

In recent years, the use of distributed generation has been widely increased. The purpose of using this type of system is to increase power quality, reduce transfer costs and in general optimization of generation network, distribution and transmission. Obviously, the system reliability is an important issue in system design and in its implementation. One of the important reasons is that with increasing competitive market, consumers concerns more about power quality [1, 2].

Usually in designing network, the generated power is more than the requested power to increase network reliability. Network restructuring after the fault is difficult. Therefore, the network is looking for a way to cut costs and provide acceptable levels of reliability for the system in the competitive market.

Distributed generation (DG) seem to be valuable in the networks during the fault, the faulted area can be isolated and DG can provide the power of this area so DG can increase reliability of system and reduce or prevent power of interruptions. Recently, another method for DG aggregation in the network, especially LV grid is presented and called microgrid. This makes positive influence on the reliability of the system [4].

Microgrid (μG) is a LV network with a source of small-scale production, storage devices and loads have an operation that is coordinated with each other [1, 2]. Microgrid can be fuel cell or wind turbines or PV they can generate small power like several KW or they can be a larger generators such as 10 MW some generators simultaneously produce heat and power together for gaining more efficiency. In normal state microgrid has connection to the network and they have energy exchanged between each others. Island mode occurs when some faults occurs in the network. In this case, microgrid disconnects from network and working in islanding state. In this state, the DG should be able to produce the power that is needed for the microgrid, otherwise, the central control center switches off some loads, which are less important in DG.

In this article, we examine the effect of the elements that are repairable or non-repairable on parameters MTTFF, MTTF As an important indexes for analyzing the system reliability.

MTTF represents the average time between failures in systems or it is the time of system loss. Sometimes to avoid confusion, the Mean time between failure (MTBF) and mean up time (MUT) is used instead of that but MTTFF represents the average amount of time for the first fault of system since it is start operation [3].

Section II explains the basic systems structure using Markov approach. Section III examines the introduced system in section II on the microgrid has been done and has numerically analyzed. In Section IV the results has been presented.

II. REVIEWS OF THE BASE SYSTEM WITH TWO ELEMENTS

Microgrid is a collection of series and parallel systems. MTTFF and MTTF have been analyzed in both networks configurations. Two states have been considered for these systems: Repairable or non-reparable.

A. Repairable systems

1) Parallel Systems: system structure and Markov model for parallel and repairable systems have been demonstrated in Fig. 1.

a)

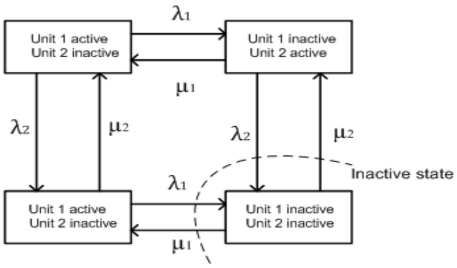


Figure 1. Parallel system structure

The exchange state of random probability matrix is very suitable for determination of states. For this purpose, a vector of probability is defined such as when the matrix is multiplied by the random change of state it will not change. Therefore:

$$\alpha P = \alpha \tag{1}$$

Where α is a matrix, which its dimensions are 1 × n. n is the number of rows of p matrix. With this explanation the P matrix of this system is:

$$P=\begin{pmatrix} 1-\lambda_1-\lambda_2 & \lambda_1 & \lambda_2 & - \\ \mu_1 & 1-(\lambda_2-\mu_1) & - & \lambda_2 \\ \mu_2 & - & 1-(\lambda_1-\mu_2) & \lambda_1 \\ - & \mu_2 & \mu_1 & 1-(\mu_1-\mu_2) \end{pmatrix} \quad (2)$$

For obtaining MTTF, the Q matrix should be discovered. Row and column number 4 can be omitted so we have

$$Q=\begin{pmatrix} 1-\lambda_1-\lambda_2 & \lambda_1 & \lambda_2 \\ \mu_1 & 1-(\lambda_2-\mu_1) & - \\ \mu_2 & - & 1-(\lambda_1-\mu_2) \end{pmatrix} \quad (3)$$

Q matrix is used for obtaining the average number of time steps before system enters in steady state mode for the continuous process of Markov method the obtained average time of MTTF method has been used. It is shown in "(4)"

$$M=(I-Q)^{-1} \quad (4)$$

Which the term M_{ij} is average time of system which has been in j state before entering the steady state in circumstances as the system process has been started from state i. if state 2 is assumed as a operational state. For parallel system MTTF is

$$MTTF_R=m_{21}+m_{22}=(\lambda_1\mu_2+\mu_1\lambda_2+\mu_1\mu_2)/(\lambda_1\lambda_2(\mu_1+\mu_2)) \quad (5)$$

b) Calculation of MTTFF: calculation for MTTFF is more complicated than MTTF and it obtained by "(6)"

$$MTTFF=P_+(0).(-R_{11})^{-1}.U_K \quad (6)$$

R_{11} is a sub matrix of R matrix and it represents the transition of the success state into success state. $P_+(0)$ is the probability vector of success state for primary state (all the active elements) and U_k is vector with unit of k, which is equal to the number of successes state:

$$R_{11}=\begin{pmatrix} -(\lambda_1+\lambda_2) & \lambda_1 & \lambda_2 \\ \mu_1 & -(\mu_1+\lambda_2) & 0 \\ \mu_2 & 0 & -(\lambda_1+\mu_2) \end{pmatrix}$$

$$P_+=\begin{pmatrix}1 & 0 & 0\end{pmatrix} \qquad U_K=\begin{pmatrix}1 & 1 & 1\end{pmatrix}^T \quad (7)$$

MTTFF for this system is

$$MTTFF_R=\frac{\mu_1\lambda_1+\lambda_1\lambda_2+\mu_2\mu 1+\lambda_2\mu_2+\lambda_1^2+\lambda_2\mu_2+\lambda_1^2+\lambda_1\mu_2+\mu_1\lambda_2+\lambda_2^2}{\lambda_1\lambda_2(\lambda_1+\mu_1+\lambda_2+\mu_2)} \quad (8)$$

2) Series systems: structure and markov model is demonstrated in Fig. 3

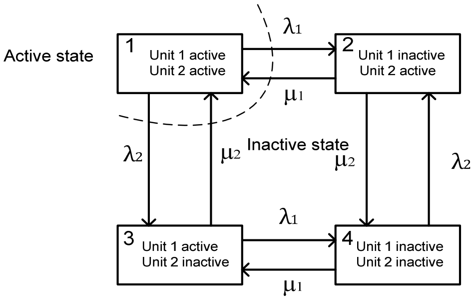


Figure3. Series system structure

In this state, modes 2, 3, 4 are not in working states. In addition, by the value of P matrix in "(2)" the Q matrix is calculated by:

$$Q=(1-\lambda_1-\lambda_2)$$

a) Calculation of MTTF: Considering the "(4)" the MTTF is

$$MTTF=1/(\lambda_1+\lambda_2)$$

b) Calculation of MTTFF: considering the "(6)" the MTTFF is

$$R_{11}=-(\lambda_1+\lambda_2) \qquad P_+(0)=1 \qquad U_K=1$$

As result

$$MTTFF=P_+(0).(-R_{11})^{-1}.U_K=1/(\lambda_1+\lambda_2)$$

B. *Non- repairable systems*

For repairable systems, MTTF is equal to MTTFF .because when system experiences its first fault it cannot exit from that state.

1) Parallel systems: reliability of non-repairable parallel system is:

$$R_{SYS}(t)=P_S=e^{-\lambda_1 t}+e^{-\lambda_2 t}-e^{-(\lambda_1+\lambda_2)t}$$

According to the definition

$$MTTF=\int_0^\infty R_{SYS}(t)dt=\frac{1}{\lambda_1}+\frac{1}{\lambda_2}-\frac{1}{\lambda_1+\lambda_2}$$

So

$$MTTF_N=MTTFF_N=1/\lambda_1+1/\lambda_2-1/(\lambda_1+\lambda_2) \quad (9)$$

2) Series systems: reliability of non-repairable series systems

$$R_{SYS}=P_s=e^{-(\lambda_1+\lambda_2)t}$$

So

$$MTTFF=MTTF=\int_0^\infty R_{SYS}(t)dt=\frac{1}{\lambda_1+\lambda_2}$$

C. *Similarities and differences between MTTF and MTTFF in series and parallel state*

It is clear that MTTF and MTTFF in repairable state in systems should be different because systems will return to success state after repair, when number of success state is greater than one. In special state, which there is, just one success state (series state) system returns to the similar state before repairing and MTTF is equal to MTTFF.

III. ANALYZING OF MICROGRID MODEL IN CONNECTION AND ISLANDING STATE

Microgrids usually work in two states. One of them is in connection state and the other one is in islanding state. Therefore, MTTF and MTTFF are evaluating in two states. Schematic of a microgrid is shown in Fig. 5.

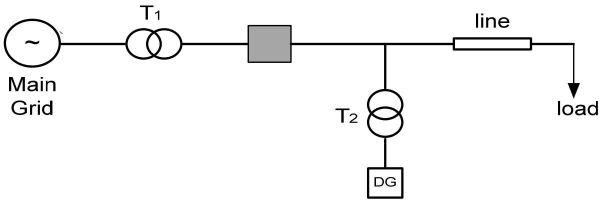
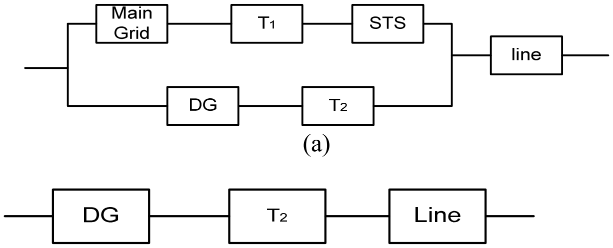


Figure 5. Microgrid

Reliability Block diagram in microgrid is illustrated in Fig. 6.



(a)

(b)

Figure 6. Reliability scheme of a microgrid (a) connection mode (b) an islanding mode

A. *Non-repairable model of system:*

1) In connection mode: according to reference [3] MTTF value is obtained from

$$MTTF = \int_0^{\infty} R_{SYS}(t)\,dt$$

Reliability is calculated by the "(10)"

$$R_{SYS}(t)=(P_{MG}.P_T.P_{STS}+P_{DG}.P_T-P_{MG}.P_{DG}.P_T^2.P_{STS}).P_L \tag{10}$$

In "(10)" the probability of success for both of transformers assumed to be equal and Probability of success for element i obtained by "(11)"

$$P_i = e^{-\lambda_i t} \tag{11}$$

If failure rate has been assumed λ_{DG}=0.02f.year^{-1} and for main grid λ_{MG}=0.024 f.year^{-1} and $\lambda_L=\lambda_{STS}=\lambda_T$=0.01 f.year^{-1} respectively. The value of MTTF is equal to 31.614 year^{-1} that is the same with the value of MTTFF.

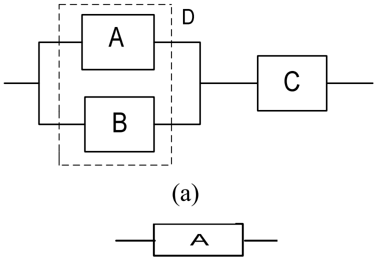
2) In Islanding mode: according to Fig. 6 the value of reliability is obtained by "(12)"

$$R_{SYS}(t)=P_{DG}.P_T.P_L \tag{12}$$

And by "(12)" the value of MTTF is 22.73 year^{-1}.

By comparison between two modes 2 and 1 it is clear that MTTF in islanding mode is lower than Connection mode.

B. *Repairable model of system:* system in Fig. 6 is simplified and presented in Fig. 7



(a)

(b)

Figure7. Simplified Fig. 6

1) In connection mode: Fig. 7 and also the calculation in section II represents that the value of MTTF and MTTFF can be obtained by mathematical operation.

a) *Calculating of MTTF*

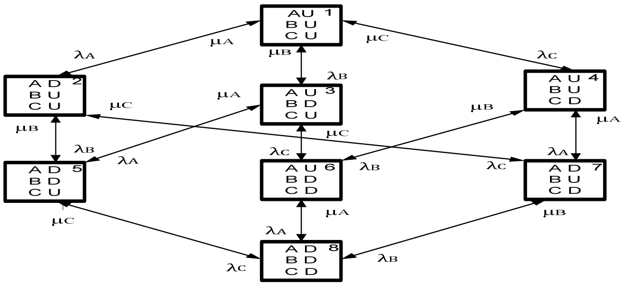


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Figure (8) state space diagram for three-member system. U represents the Up state and D represents down

P matrix is:

$$\begin{pmatrix}
1-(\lambda_A+\lambda_B+\lambda_C) & \lambda_A & \lambda_B & \lambda_C & - & - & - & - \\
\mu_A & 1-(\mu_A+\lambda_B+\lambda_C) & - & - & \lambda_B & - & \lambda_C & - \\
\mu_B & - & 1-(\mu_B+\lambda_A+\lambda_C) & - & \lambda_A & \lambda_C & - & - \\
\mu_C & - & - & 1-(\mu_C+\lambda_A+\lambda_B) & - & \lambda_B & \lambda_A & - \\
- & \mu_B & \mu_A & - & 1-(\mu_A+\mu_B+\lambda_C) & - & - & \lambda_C \\
- & - & \mu_C & \mu_B & - & 1-(\mu_B+\mu_C+\lambda_A) & - & \lambda_A \\
- & \mu_C & - & \mu_A & - & - & 1-(\mu_A+\mu_C+\lambda_B) & \lambda_B \\
- & - & - & - & \mu_C & \mu_A & \mu_B & 1-(\mu_A+\mu_B+\mu_C)
\end{pmatrix}$$

Active states in system are state 1 and 2 and 3 and the other state is inactive states and according to Q has been made as follows.

$$Q = \begin{pmatrix} 1-(\lambda_A+\lambda_B+\lambda_C) & \lambda_A & \lambda_B \\ \mu_A & 1-(\lambda_A+\lambda_B+\lambda_C) & 0 \\ \mu_B & 0 & 1-(\mu_B+\lambda_A+\lambda_B) \end{pmatrix}$$

By “(4)” the value of MTTF is obtained by μ_{MG} =$\mu_{\mu G}$=2f.year^{-1} and μ_T=4f.year^{-1} and μ_{STS}=μ_L=12f.year^{-1} the value of MTTF is equal to 77.2112 years^{-1}.

b) *calculating of MTTF:*

By using “(6)” value of MTTFF is obtained 88.4721 years^{-1}.

2) *In islanding mode:*

In islanding mode and because of all the series elements the value of MTTF and MTTFF are the same and they are equal to the value, which obtained in non-repairing mode.

$MTTF_R=MTTFF_R=MTTF_N=MTTF_N=1/(\lambda_{DG}+\lambda_T+\lambda_L)$ =22.7.f.year^{-1}

C. *The effect of repair rate*

As was observed the repair rate (μ) has no effect on MTTF and MTTFF in islanding mode and in non-repairable elements which means by varying the value (μ) the value of MTTF and MTTFF not change.

The effect of repair rate in connection mode and in repairable systems has been analyzed. By simplification of system that is shown by dash in Fig. 7-a value of $MTTF_R$, $MTTFF_R$ can be deduced.

$$MTTF_R = MTTFF_R = \frac{1}{\lambda_D + \lambda_C}$$

$MTTF_R$ is equal to $MTTFF_R$ .it happened because of after the simplification in both series system and according to section II the value of $MTTF_R$ is equal to the value of $MTTFF_R$.

According to equations obtained in section II if the value of μ_1, μ_2 closes to zero then:

$$\lim_{\substack{\mu_1\to 0\\ \mu_2\to 0}}(MTTFF_R - MTTFF_N) = \lim_{\substack{\mu_1\to 0\\ \mu_2\to 0}}\left(\frac{(\lambda_1+\lambda_2).\mu_1.\mu_2+\lambda_1.\lambda_2.(\mu_1+\mu_2)}{\lambda_1.\lambda_2.(\lambda_1+\mu_1+\lambda_2+\mu_2).(\lambda_1+\lambda_2)}\right)$$

According to the limit, this explained in equation the Numerators close to, zero while the Denominator is constant. Then:

$$\lim_{\substack{\mu_1\to 0\\ \mu_2\to 0}}(MTTFF_R - MTTFF_N) = 0$$

Means as closer the value of μ_1, μ_2 to zero the value of $MTTFF_R$ is closer to $MTTFF_N$. In “8” and “9” If $\mu_2=\mu_1$ and $\lambda_2=\lambda_1$ then:

$$MTTFF_R = \frac{\mu^2+4\mu\lambda+3\lambda^2}{2\lambda^2(\mu+\lambda)}, \quad MTTFF_N = \frac{3}{2\lambda}$$

If μ ⟶ 0 Then:

$$MTTFF_N = MTTFF_R = \frac{3}{2\lambda}$$

By closing, the value of μ to zero the value of $MTTFF_R$ is closing to $MTTFF_N$. In “(5)”, “(9)” by assuming the same variables

$$MTTF_R = \frac{\mu+2\lambda}{2\lambda^2} \qquad MTTFF_N = \frac{3}{2\lambda}$$

If by μ⟶0

$$MTTF_R = \frac{1}{\lambda} \qquad MTTFF_N = \frac{3}{2\lambda}$$

The value of $MTTF_N$ is not equal to the value of $MTTF_R$

IV. CONCLUSIONS

As seen in this article maintenance has a considerable effect on the MTTF and MTTFF. As shown on section III in islanding state, repairable system or non-repairable system have no significant effect on MTTF and MTTFF and by varying the value of MTTF and MTTFF remain constant. However, in the connection mode the value of MTTF and MTTFF is a function of repairable or non-repairable systems. In addition, the results prove the value of MTTF in islanding state is less than the value of MTTF in connection state.

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