Reliability Assessment of Power Distribution Networks Considering Covid-19 Pandemic

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Reliability Assessment of Power Distribution Networks Considering Covid-19 Pandemic

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Abstract— **The reliability of power distribution networks can be threatened due to the health of repair crews. Covid-19 is a nowadays challenge that affects the health and the availability of repair crews. Monte Carlo simulation is implemented in this paper to evaluate the reliability of power distribution networks considering Covid-19. This paper alerts the power distribution companies to consider some strategies to prevent the growth of expected energy not served (EENS) during the pandemics era such as Covid-19.**

Keywords— Covid-19, Monte Carlo, Pandemic, Power distribution networks, Reliability

I. Introduction

The world faced Covid-19 pandemic at the beginning of 2020. Covid-19 as an emergency case not only threats the public health of the world but also affects the operation of power systems. Energy consumption, load forecasting, energy market policy and demand ramp rate are new challenges with Covid-19. Energy consumption trends have been changed during this pandemic, which is studied in many recent works such as [1]-[4]. These works investigate the consumption of different loads before/after Covid-19 and report the increased residential loads consumption and the decreased total load consumption after the commence of pandemic. Short load forecasting with last input data including weather, time and previous consumption yields higher error [5]. So, it is necessary to propose a new tool to predict the load. In [6], the impact of Covid-19 on the energy market with a case study is investigated and it is shown the costly thermoelectric generation is taken out of the market due to the load reduction. Consequently, the wholesale energy market is decreased. Defiantly, Covid-19 affects other aspects of power network and industry that will be investigated late.

Reliability is the other important concern of the power system considering Covid-19 [7]. Time to repair (TTR) is one of the main factors in reliability evaluation. The performance quality of repair teams affects the TTR of a damaged component. Although there are several repair teams to support the network all the time. However, the number of crews of each repair team in most of the distribution companies is often considered without reserve. Therefore, if a repair crew is isolated due to Covid-19, it is difficult to consider an alternative one. In the other hand, the alternative crew is either not enough experienced and professional men or with the pressure of long work shifts. These reasons lead to increased TTR. Hence, reliability assessment of power distribution networks under these circumstances is vital to minimize the interruptions of supply to customers.

In recent years, the resilience study of power systems is highlighted and different methods are proposed to calculate the resilience of power systems. The reason is that previous reliability tools were not enough efficient. For example, in resilience study, the dependency of other infrastructures such as water network on power network is significant [8], [9]. Therefore, Covid-19 and the dependency of TTR of damaged component on the health of repair crews convince the operator and planner to review the reliability assessment of power distribution networks. Monte Carlo simulation is a powerful tool in the evaluation of power systems reliability. One advantage of Monte Carlo is that it can evaluate the reliability of a system considering different distribution functions. Different papers such as [10],[11] calculate the reliability of power systems considering different probability functions. Therefore, Monte Carlo simulation is a suitable tool to evaluate the reliability of power distribution networks considering Covid-19 that affect TTR of damaged components. In other words, in this condition, TTR of the damaged component is no longer in the form of the previous TTR.

This paper evaluates the reliability of power distribution networks considering Covid-19 with Monte Carlo simulation. In other words, the health and availability of repair crews are considered in the reliability of power distribution networks. The remainder of this paper is organized as follow. Section II presents the modelling the health (availability) of the repair crews considering Covid-19. Section III explains the implementation of Monte Carlo simulation to evaluate the reliability of power distribution networks considering Covid-19. Numerical results is presented in section IV. Furthermore, in section IV, some solutions to minimize the effect of Covid-19 on the reliability are proposed and each of them is simulated and studied. Finally, section V concludes the paper.

II. Modelling the Health (Availability) of Repair Crews Considering Covid-19

TTR of damaged components strongly depends on the availability and the proficiency of the repair crews. In this paper, the probable isolation of repair crews due to Covid-19 are considered to evaluate the reliability of power distribution networks. There are some assumptions as below to model the availability of repair crews. These assumptions are considered based on the working shifts of repair crews and experiments that resulted during Covid-19 pandemic.

1- There are three repair teams to support the network and each repair team includes two crews.

2- The shift work of each repair team is 8 hours per day.

3- Each crew can be infected with Covid-19 with a predetermined probability every day.

4- If a crew is infected, his/her disease will be confirmed one day later. He/she also must be isolated for 14 days.

5- Recovered Covid-19 patients will have immunity for three months.

6- Each crew can only get infected with Covid-19 twice.

7- There are always reserves for Covid-19 infected crews. But, TTR of damaged components under this circumstance will be increased.

8- Only one repair crew start and finish the repairing of a damaged component.

To better understand assumption 7, consider Fig. 1 that demonstrates the increased TTR of a damaged component due to the unavailability of the main crew(s) of a repair team. Multipliers that are more than one model the increased TTRs. In other words, *x/y* increases TTR if one/two of the crews of the responsible repair team for repairing the damaged component is/are unavailable due to Covid-19 and one/two other alternative(s) is/are available.

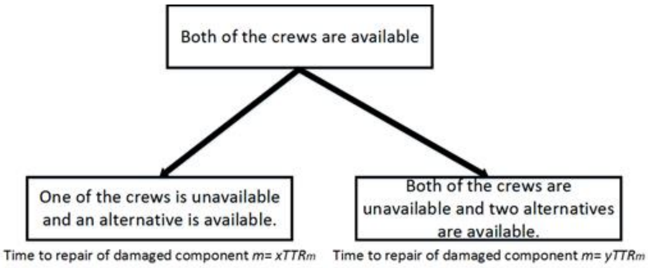

Fig. 1. The increased TTR of a damaged component due the health of the crews of a repair team

Fig. 2 shows a Pseudo-code that describes the steps of modelling of the health (availability) of crews due to Covid-19 within a year.

```
default: all crews are available for all days.
d (day index)=1
for all repair teams, do
    for all crews, do
        CI (Covid-19 index)=0;
        while d ≤365
            if (rand ≤ Cr (Covid-19 infection probability)) & if (CI ≤ 2)
              CI=CI+1;
              The crew is not available for the next 14 days.
                d=d+90;
              else
                d=d+1;
            end if
        end while
    end for
end for
```

Fig. 2. Pseudo-code of crews availability considering Covid-19

III. Monte Carlo simulation to evaluate the reliability of power distribution networks

```
for all iterations, do
    EENS = 0;
    assume all the components are available in all hours of the year
   for all components, do
        calculate TTF with (1)
        if TTF ≤ 8760
          determine the unavailability of the component during the year
          determine TTR of the component with the proposed algorithm
        end if
    end for
    h = 0;
    while h (hours) ≤ 8760
    determine the connectivity of each load
          h=h+1;
    end while
          calculate EENS
end for
          calculate average EENS
```

Fig. 3. Pseudo-code of Monte Carlo simulation

Monte Carlo simulation is a well-known tool in the reliability evaluation of power distribution networks. This tool can be effectively used to predict the behavior of components in the future with the failure and repair probability distribution functions. Finally, reliability indexes can be calculated through several iterations. In many works, failure and repair probability distribution functions are modeled with exponential distribution functions. But, historical data shows this assumption is not confirmed all the time, especially in some cases that an external factor suddenly affects the system such as Covid-19 that increase TTR of damaged components due to the health and proficiency of repair crews. In this paper, time to failure (TTF) of each component is calculated with (1).

$$TTF = -\frac{1}{\lambda}\ln(n) \tag{1}$$

where λ and $n\lambda$ are failure rate and a random number between 0 and 1, respectively. Furthermore, expected energy not served (EENS) is chosen as the reliability index to evaluate the reliability of power distribution networks. This index is formulated as (2).

$$EENS = \sum_{t=1}^{8760}\sum_{i=1}^{N_l} l_{i,t}u_{i,t} \tag{2}$$

where t, i and N_i are time index, load index and number of loads, respectively. $l_{i,t}$ and $u_{i,t}$ are amount of load and connectivity state of load i in hour t. $l_{i,t}$ is zero if a load is supplied by the network. Otherwise, it is one. It should be noticed, some reliability indices such as system average frequency index (SAFI) will not affected due to Covid-19. In other words, this index does not depend on the TTF of damaged components.

Considering the impact of Covid-19 on the availability of repair crews, the algorithm of Monte Carlo simulation for reliability evaluation of power distribution networks is depicted in Fig. 3. In this paper, 1 year is chosen as the study period for reliability evaluation of power distribution networks considering Covid-19.

IV. NUMERICAL RESULTS

Reliability evaluation considering Covid-19 is applied to an 8 bus distribution network that is shown in Fig. 4. This network has seven segments (distribution lines). The failure rate and repair time of each segment are tabulated in Table I. Furthermore, Table II gives the peak load of each node of this network. Three different load levels and their durations within a year is also provide in Table III. Most of these sets of data are extracted from [12].

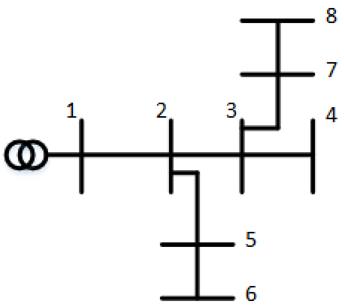

Fig. 4. The 8 bus distriution network

TABLE I. FAILURE RATE AND REPAIR TIME OF DIFFERENT SEGMENTS OF DISTRIBUTION NETWORK

Distribution segment	Failure rate, λ (f/yr.)	Repair time (hour)
1	0.4	4
2	0.2	2
3	0.3	3
4	0.5	5
5	0.2	3
6	0.1	3
7	0.1	3

TABLE II. LOADS OF NODES OF EIGHT BUST DISTRIBUTION NETWORK

Node	Load (kW)
1	0
2	1000
3	700
4	400
5	500
6	300
7	200
8	150

TABLE III. DIFFERENT LOAD LEVELS

Load level	Duration (h)	% of peak load
1	340	1
2	5500	0.4
3	2920	0.5

Various cases with different parameters of *Cr* (Covid-19 infection probability), *x* and *y* (multipliers of increased TTR as in Fig. 1) are considered to evaluate the reliability of the mentioned power distribution network during a year. The results are illustrated in Figs 5 and 6. In some cases, *Cr* is calculated based on the real data that are extracted from [13]. To calculate the daily *Cr*, daily new cases of Covid-19 in Iran during 21/3/2019-20/3/2020 per the population of Iran are considered.

According to Fig. 5, when *Cr* is considered as 0.001, EENS is increased by 5.29% in comparison with the case where EENS is evaluated without Covid-19.

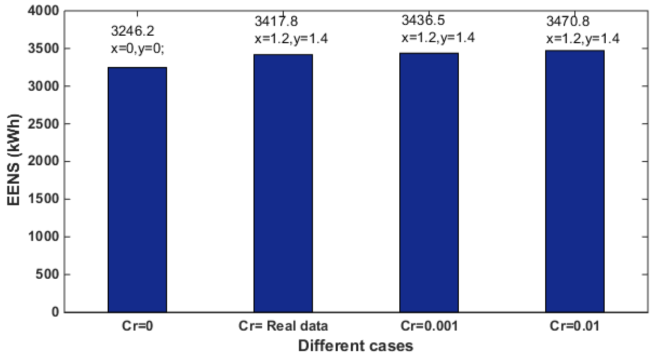

Fig. 5. Reliability evaluation results without and with Covid-19 (when *x*=1.2, *y*=1.4).

It is worth mentioning, *Cr*=0.001 is enough large that causes the infection of crews to Covid-19 and affects EENS. This is confirmed when EENS is calculated with *Cr* =0.01. In other words, EENS resulted from *Cr*=0.001 is so close to EENS resulted from *Cr*=0.01. Furthermore, the raising of EENS with real data (for calculating *Cr*) is also close to the other amounts of *Cr*. This confirms the appropriate assumption of *Cr*s in the proposed method for evaluating the reliability considering Covid-19.

According to Fig. 6, when TTR of damaged element is equal to *x*=1.4 and *y*=1.6, EENS is increased by 4.54%, 4.6% and 4.1% for *Cr*= real data, *Cr*=0.01 and *Cr*=0.001, respectively compared to the previous case (Fig. 5). It is shown increased TTR due to the unavailability of crews can threaten the reliability of power distribution networks.

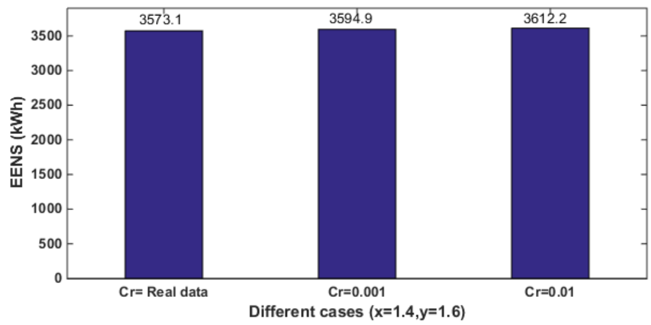

Fig. 6. Reliability evaluation results with Covid-19 (when *x*=1.4, *y*=1.6).

It should be noticed that increased TTR results only from the unavailability of the repair crews in this paper. But, Covid-19 can affect other parameters and finally increases TTR of damaged components. Some of these parameters can be listed below.

- If the workers in the stock infect Covid-19, the delivery of equipment for repair or replacement of damaged components will be affected.
- If the responsible man of the required equipment for repairing the damaged component such as crane infect Covid-19, TTR of the damaged component will be increased. Although, calculating the increment rate of TTR is complicated.

Therefore, *x* and *y* are considered larger and the reliability of the power distribution network is assessed again. According to Fig.7, EENS (with different amounts of *Cr*) is increased at least by 16% in comparison with the reliability is calculated without Covid-19. So, in order to avoid this increment of EENS, the parameters that affect reliability and also Covid-19 will affect them must be identified and managed.

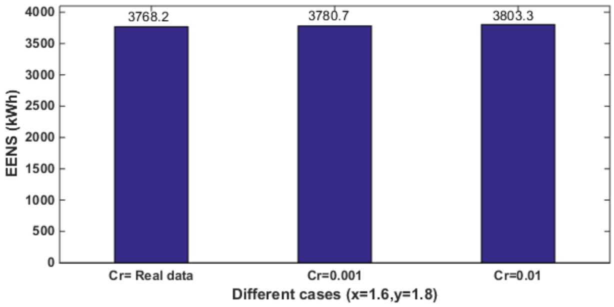

Fig. 7. Reliability evaluation results with Covid-19 (when x=1.6, y=1.8).

Hence, distribution companies must be worried about the reliability of their networks during pandemics such as Covid-19. They should propose efficient solutions to overcome the effect of Covid-19 on reliability. Some solutions are listed below:

1. The alternative repair crews must be trained to decrease TTR.
2. Providing a healthy environment for repair crews with minimum communication with the others.

To investigate the impact of the solutions on the reliability, each of them is simulated. To model the first solution, it is assumed that the train of the alternative repair crews causes the parameters x and y are reduced to 1.1 and 1.2, respectively. The result of this simulation is shown in Fig. 8. EENSs resulted from all different amounts of Cr are close to EENS without Covid-19. In other words, with providing and training the alternative crews, the impact of Covid-19 on the reliability is minimized.

To study the impact of the second solution on the reliability, the daily Covid-19 infection probability (*Cr*) is considered as only 0.2*Cr* with the real data. Although, decreasing *Cr* is difficult for distribution companies. But, this will be reachable with appropriate decisions such as the mandatory wearing mask of repair crews and providing a healthy working environment. Fig 9 shows the result of this case with different amounts of *x* and *y*. According to Fig. 9, EENS with even x=1.6 and y=1.8, is so close to EENS without Covid-19.

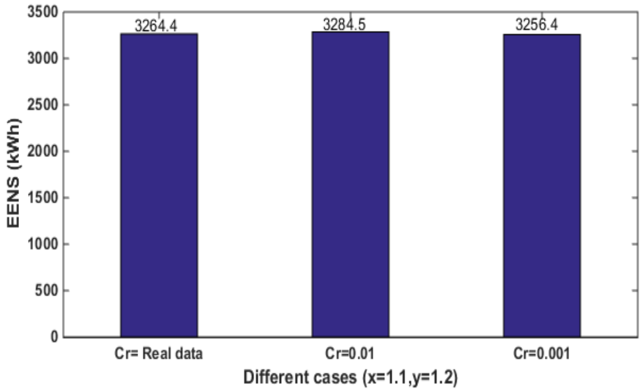

Fig. 8. Reliability evaluation results for solution 1

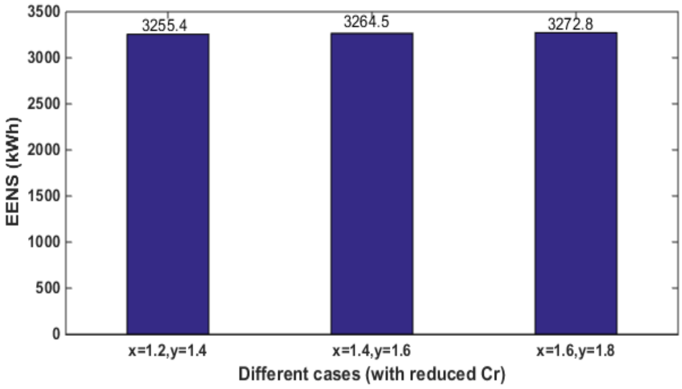

Fig. 9. Reliability evaluation results for solution 2

V. CONCLUSION

The increased TTR of damaged components in power distribution networks resulted from the unavailability of repair crews due to Covid-19 was modeled in this paper. In this condition, the reliability of power distribution networks was evaluated based on Monte Carlo simulation. A test network is chosen and various cases including different parameters including the probability of Covid-19 infection and increased TTR are considered to study the reliability of power distribution networks. Regarding different amounts of daily Covid-19 infection probability (*Cr*) and also using real data to calculate this parameter, EENS as the reliability index was raised by approximately 5% if only x=1.2, y=1.4. Larger x and y that are not unexpected in a real network can increase EENS even more. Finally, some solutions for distribution companies are proposed to minimize the effect of Covid-19 on the reliability of networks. Each solution was studied and it was shown that the impact of Covid-19 on the reliability of power distribution networks can be minimized or even ignored with them.

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