Validity of Using a Global Repair Service Model in Power System Reliability Studies

C. J. Zapata, *Member, IEEE*, and M. A. Rios, *Member, IEEE*

***Abstract*--Traditionally, repairs has been modeled in power system reliability as part of the component reliability models; an alternative way is to represent them by means of queuing theory concepts. One of the advantages of this approach is that it allows assessing the performance of crews, a feature not offered by any other method. However, the application of this modeling approach arises the following question: ¿what is the correct way to generate the times to repair, using a global model for all components or using one for each component or component class? To reply this question, in this paper reliability of a power transmission system is assessed using both approaches and considering for power transformers the cases of repair, replacement with a local spare and replacement with a spare taken from a remote location. The conclusion is that if repair durations of the components are very different is not valid to use a global model for generating the repair times for all components, i. e. the approach commonly used in QT is not valid here; instead, it is necessary to generate them using a model for each component or component class and this demands more computational time.**

***Index Terms*-- Maintenance, Poisson processes, power system reliability, power system simulation, queuing analysis.**

I. Nomenclature

β : Shape parameter of a power law model
C_D : Congestion in duration
d : Duration of a failure scenario
Δ : Increment of an index
f_i : A failure i
λ : Scale parameter of a power law model
$\lambda(t)$: Intensity function of a point model
n : Number of power system components
n_f : Number of failures
n_x : Number of failure scenarios of order x
P : Probability of
r_i : A repair i
ttf : Time to failure
ttr : Time to repair
tod : Time of outage duration
tw : Waiting time
x : Number of lost components
$\bar{\ }$: Mean of

II. Introduction

A large power system is generally split into several maintenance zones or service territories for maintenance activities, as it is depicted in Fig 1. The repair process performed in each maintenance zone of a large power system is then a queuing system (QS) because each failed component queues up for a service called repair. Although this fact, repairs have been traditionally represented in power system reliability studies as part of the component reliability models [1]-[2], an approach that unrealistically assumes that [3]:

1. There is a repair team dedicated to each component, i. e. the repair resources are unlimited.
2. Repairs on a given component are independent of the repairs performed on other ones.

These authors proposed in [4] a method for reliability assessment of bulk power transmission systems that represents the repair process using queuing theory (QT) concepts to overcome these deficiencies. So, the purpose of this paper is to study in detail the correct way to generate the ttr in this method.

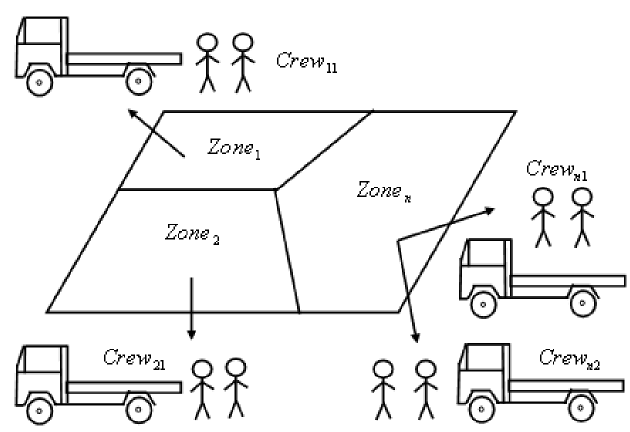

Fig. 1. Maintenance zones in a power system

III. QT Representation of the Repair Process [5]-[8]

Fig. 2 shows the QT representation of the repair process performed in a maintenance zone of a power system. For this QS, the following is defined:

- Input process:The sequence of component failures.
- Service process: The sequence of $ttr's$.
- Output process: The sequence of repairs. It is the result of the interaction between the input and service processes.

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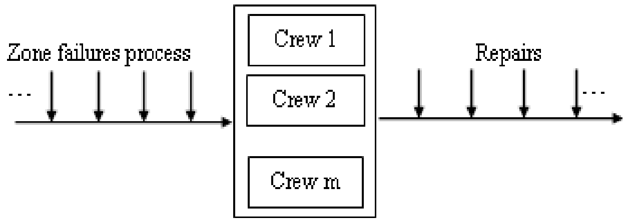

Fig. 2. QT model for the repair process in a maintenance zone

In Kendall's notation, this QS is described as:

$$G / G / m / \infty / FCFS$$

The first and second "G" indicate that both the input and service processes are general probabilistic models. m, ∞, and $FCFS$ indicate, respectively, the number of crews, the system capacity and the queuing discipline "First Come – First Served". The capacity of this system is infinite, because all the failures have to be repaired.

The input and service processes allow solving the QS; their models are built using operating data. Most preferred models for these processes include probability distributions and the Homogeneous Poisson Process (HPP); however, a more general approach is to use stochastic point process (SPP) models, i. e. Renewal processes (RP) or Non-Homogeneous Poisson Processes (NHPP).

Repair durations, i. e. the $ttr's$, are then generated from the service model. At this point, is necessary to define the following times:

ttr: The period required by a crew to repair a component. It includes the travel time to the place where the component is located and the time to take actions that lead to restore the component to the available state.

tw: The period a failed component has to wait until a crew is free to repair it. It arises due to the limitation on resources for repairs (personnel, trucks, tools, etc).

tod: The period a component is out of service due to a failure. It is computed as follow:

$$tod = tw + ttr \quad (1)$$

A detailed description of the procedure to build the repair service model from operating data and the problems that arise due to poor recording practices is given in [9].

IV. Problem Statement

When applying QT approach for modeling the repair process performed in a power system the following question arises: ¿what is the correct way to generate the $ttr's$, using a global model for all components or using a model for each component or component class?

The first approach is the most used in QT but a comment to it is that, when applied to power systems, it does not reflect the fact that times to repair can be very different from a component type or component class to other. Additionally, the repair method can produce very different repair durations.

The second approach is more detailed but it is only easy to apply inside a Monte Carlo simulation (MCS) method.

It is then the aim of this paper to compare these two modeling approaches for the service process, observing their effect on the results of a system reliability study.

V. Assessment Method

The main steps of the MCS algorithm for assessing the system reliability are:

1. Using the models that represent component failures and common mode failures, generate for a period T of one or several years the sequence of failures in each maintenance zone.
2. Using the repair service model, generate the sequence of repairs in each maintenance zone. Each failure f_i has associated a repair r_i that lasts tod_i.
3. For each high order failure scenario (HOFS) order, i. e. those with $x \geq 2$, compute the mean duration; Fig. 3, shows this concept.
4. Repeat R times steps one to three.
5. Compute the system reliability indexes (2) and (3).
6. Compute the repair service indexes (4) to (6).

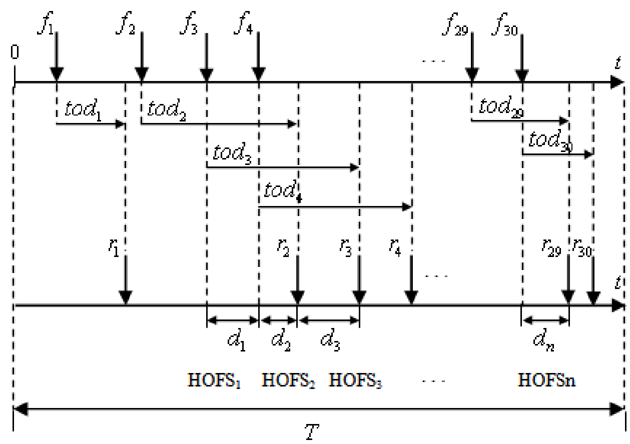

Fig. 3. The definition of high order failure scenarios

$$\overline{d}_{n-x} = (\sum_{\forall d \in (n-x)} d_{(n-x)}) / n_x \quad (2)$$

$$P_{n-x} = (\sum_{\forall d \in (n-x)} d_{(n-x)}) / (R\ T) = n_x\, \overline{d}_{(n-x)} / (R\ T) \quad (3)$$

$$\overline{tw} = (\sum_{j=1}^{n_f} tw_i) / n_f \quad (4)$$

$$\overline{tod} = (\sum_{j=1}^{n_f} tod_i) / n_f \quad (5)$$

$$C_D = \overline{tw} / \overline{tod} * 100\% \quad (6)$$

The order of a failure scenario is defined as the situation where x of n are unavailable due to failure. This is denoted as $n-x$.

A more detailed description of this MCS algorithm and indexes is given in [4]. The background for the development of this method is presented in [10]-[12].

tw, tod, C_D, allow assessing the performance of crews a feature not offered by any other method.

VI. Description of the Study

Let us to consider the occurrence of failure scenarios in the One Area IEEE Reliability Test System (RTS) [13], $T = 1$ year and 25000 realizations. The RTS is shown in Fig 4.

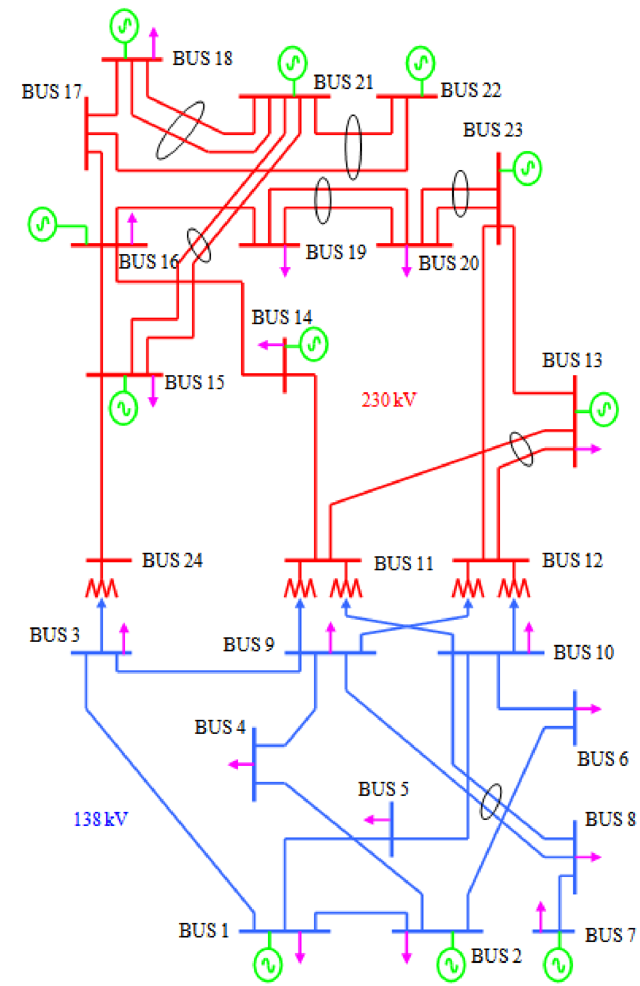

Fig. 4. The IEEE One Area RTS [13]

A. Modeling of Failures and Repairs

All failure and repair processes are represented by means of the Power Law Process (PLP) [14], a SPP model with intensity function defined by:

$$\lambda(t) = \lambda \beta t^{\beta - 1} \qquad (7)$$

When the shape parameter β of the PLP is equal to one, it is stationary and corresponds to the homogeneous Poisson Process (HPP), i. e. an exponential RP; on the contrary, it is non-stationary, with positive tendency if $\beta > 1.0$ and negative tendency if $\beta < 1.0$.

The scale parameter λ of the component failure models is equal to the permanent failure rate given for them in [13]. The scale parameter λ of the repair models is explained in the next section.

It is assumed for in cases of study that all failure and repair processes are stationary; thus, the shape parameters (β_F, β_R) of all models are equal to one.

B. Component Repair Durations

Repair data for RTS components is shown in Table I.

TABLE I
MEAN TIME TO REPAIR FOR RTS COMPONENTS [13]

Component	[Hours]
Line A10 (138 kV)	35
Line A1 (138 kV)	16
Other 138 kV transmission lines	10
230 kV transmission lines	11
Power transformers	768

Power transformer repair durations are extremely long compared to the ones of transmission lines. This, long duration (768 hours=32 days) can be reduced if the utility has a local spare or if a spare is taken from a remote location. Thus, it is also considered in this study the alternatives of replacing a failed transformer by a local spare in one day (24 hours) or by means of a spare transported from a remote location in 5 days (120 hours).

C. Cases of Study

For the comparison of the two modeling approaches for the repair service, let us to define the following cases of study:

- Case 1: There is a particular repair model for each component. The scale parameter λ for each component repair model equal to inverse of the mean time to repair shown in Table I.
- Case 2: There is a global repair model for all components.

The global service model required for case 2 is obtained from the assessment of case 1 because it computes the $\overline{ttr}$ for each zone. Thus, λ of the global model of a given zone in case 2 is equal to the inverse of $\overline{ttr}$ for that zone in case 1.

A single maintenance zone for the system under study is adopted in order to involve the different repair times of the components present in the RTS.

Reliability assessments are performed for the situation of repair of power transformer, replacement with local spare and replacement with a spare taken from a remote location.

D. Results – Repair of Power Transformer in r=768 hr

Table II shows that although $\overline{ttr}$ generated with both modeling approaches are almost equal, the indexes for repair service obtained with the global service model are very different to the ones obtained when using a repair model for each component.

TABLE II
INDEXES OF REPAIR SERVICE – r = 786 HOURS

Case	$\overline{ttr}$ [Hours]	$\overline{tod}$ [Hours]	$\overline{tw}$ [Hours]	C_D [%]
1	17.1402	23.4766	6.3364	26.9903
2	17.1078	17.5535	0.4458	2.5394
Δ%	-0.1890	-25.2298	-92.9645	-90.5914

Tables III and IV show how the prediction of occurrence of failures scenarios is very different with both modeling approaches. The global service modeling is “optimistic” because only predict scenarios up to order four. With exception to the normal operating condition ($n-0$), the indices predicted with both methods are very different. Thus, considering only this operating condition could lead to the erroneous conclusion that both methods produce the same results.

TABLE III
DURATION OF FAILURE SCENARIO [HOURS] – r = 786 HOURS

Order	Case 1	Case 2	Δ%
n-0	620.3999	620.3280	-0.0116
n-1	13.6949	16.6467	+21.5540
n-2	45.2803	16.5022	-63.5555
n-3	190.9638	15.0442	-92.1220
n-4	233.6654	13.7462	-94.1171
n-5	218.0553	---	---
n-6	228.8435	---	---
n-7	199.4374	---	---
n-8	244.6194	---	---
n-9	185.5321	---	---
n-10	383.5609	---	---
n-11	137.4204	---	---
n-12	7.1260	---	---
n-13	139.1885	---	---
n-14	372.1901	---	---

TABLE IV
PROBABILITY OF FAILURE SCENARIO [%] – r = 786 HOURS

Order	Case 1	Case 2	Δ%
n-0	97.5144	97.4408	-0.0755
n-1	2.0109	2.4551	+22.0896
n-2	0.2594	0.1012	-60.9869
n-3	0.1084	0.0029	-97.3247
n-4	0.0546	1.1926E-04	-99.7816
n-5	0.0274	---	---
n-6	0.0143	---	---
n-7	0.0055	---	---
n-8	0.0028	---	---
n-9	8.4718E-04	---	---
n-10	0.0011	---	---
n-11	1.2550 E-04	---	---
n-12	6.5078E-04	---	---
n-13	1.2711E-04	---	---
n-14	1.6995E-04	---	---

E. Results – Replacement of Power Transformers in r=120 hr

Table V shows the same result mentioned previously, but now the percentage of difference in the prediction of the repair process indexes has reduced considerably.

TABLE V
INDEXES OF REPAIR SERVICE – r = 120 HOURS

Case	$\overline{ttr}$ [Hours]	$\overline{tod}$ [Hours]	$\overline{tw}$ [Hours]	C_D [%]
1	12.2114	12.5913	0.3799	3.0171
2	12.1883	12.4127	0.2244	1.8079
Δ%	-0.1892	-1.4184	-40.9318	-40.782

Tables VI and VII show that now the duration of failure scenarios have been reduced appreciably with the spare taken from a remote location; also, the failure scenarios predicted with both methods almost coincide. However, for some failure scenario orders, the indices predicted with both methods are still very different.

TABLE VI
DURATION OF FAILURE SCENARIO [HOURS] – r = 120 HOURS

Order	Case 1	Case 2	Δ%
n-0	620.2902	620.2582	-0.0052
n-1	11.8522	11.9519	+0.8412
n-2	14.3308	11.8554	-17.2733
n-3	27.1614	10.5433	-61.1828
n-4	67.2317	5.9825	-91.1017
n-5	43.1603	---	---

TABLE VII
PROBABILITY OF FAILURE SCENARIO [%] – r = 120 HOURS

Order	Case 1	Case 2	Δ%
n-0	98.1747	98.1756	+9.1673E-04
n-1	1.7477	1.7629	+0.8697
n-2	0.0730	0.0603	-17.3973
n-3	0.0040	0.0012	-70.000
n-4	5.8329E-05	2.1854E-05	-62.5332
n-5	9.8540E-05	---	---

F. Results – Replacement of Power Transformers in r=24 hr

Table VIII show that now the indices predicted with both modeling approaches are similar. Tables IX and X show that now the failure scenarios predicted with both methods coincide. However, as high the order of the failure scenario, higher is the difference in the predicted indexes

TABLE VIII
INDEXES OF REPAIR SERVICE – r = 24 HOURS

Case	$\overline{ttr}$ [Hours]	$\overline{tod}$ [Hours]	$\overline{tw}$ [Hours]	C_D [%]
1	11.4813	11.7116	0.2304	1.9670
2	11.4596	11.6576	0.1980	1.6986
Δ%	-0.1890	-0.4611	-14.0625	-13.6299

TABLE IX
DURATION OF FAILURE SCENARIO [HOURS] – r = 120 HOURS

Order	Case 1	Case 2	Δ%
n-0	620.2755	620.2629	-0.0020
n-1	11.2521	11.2503	-0.0160
n-2	11.6013	11.1537	-3.8582
n-3	12.4741	10.0304	-19.5902
n-4	20.8778	6.3004	-69.8225

TABLE X
PROBABILITY OF FAILURE SCENARIO [%] – r = 120 HOURS

Order	Case 1	Case 2	Δ%
n-0	98.2817	98.2845	+0.0028
n-1	1.6596	1.6595	-0.0060
n-2	0.0573	0.0550	-4.0140
n-3	0.0014	0.0010	-28.5714
n-4	3.8133E-05	1.7261E-05	-54.7347

VII. COMPUTATION TIME COMPARISON

Table XI shows that when the assessment considers a repair model per component it uses three times more computational time than in the case of using a global repair service model.

TABLE XI
REQUIRED COMPUTATIONAL TIME [HOURS]

Repair Method of power transformers	Case 1 Model per component	Case 2 Global model
Repair	19.3437	6.7449
Replacement with spare taken from remote location	19.2495	6.7141
Replacement with local spare	19.2379	6.4468

VIII. CONCLUSION

When using a queuing representation for the repair process performed in a power system it is not valid to use a global model for generating the repair times for all components if repair durations are very different, i. e. the approach commonly used in QT is not valid here; instead, it is necessary to generate them using a model for each component or component but and this demands more computational time.

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X. BIOGRAPHIES

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