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EFFECT OF ALTERNATIVE SUPPLY, DISCONNECTING SWITCHES AND FAULT PASSAGE INDICATORS ON RELIABILITY OF RADIAL DISTRIBUTION FEEDER

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ABSTRACT

In olden days, the only aim of power system engineering was to generate and supply the power. But, now it has been extended to power quality and reliability due to customer and utility needs. The various power quality issues are sag, swell, transients, noise, flickering, harmonic distortion, frequency variation and voltage interruptions. Voltage interruptions cause power outages to the load points of customers. In modern power system networks, end users are expecting good reliable power and expectations keep rising. The effect of power outages is more in the industrial, commercial and agricultural loads than any other factor. The voltage interruptions are referred as reliability issues of power systems and it is a subset of power quality. Now-a-days, power system regulating authorities are considering the long duration interruption reliability statistics as the benchmark to identify the service quality. For a fixed number of customers and configuration, the reliability of radial distribution network can be improved either by reducing the average failure rate of system components or by reducing the average restoration time using faster restoration techniques. In this paper, an attempt is made to improve the reliability of radial distribution system by adding extra alternative supply, disconnecting switches and fault passage indicators.

KEYWORDS: Radial Feeder, Reliability, Fault Passage Indicators, Reliability Indices.

After occurrence of an active sustained fault on a radial feeder, circuit breaker of the corresponding feeder will be opened and all the load points lose their power supply. To restore the supply, the faulted portion is identified, isolated and repaired/replaced. After occurrence of the fault, the loads on feeder fall into three categories (i) loads under upstream section (ii) loads under faulted section and (iii) loads under downstream section. In case of manual operated radial feeder, the restoration of supply takes place in the following steps [2].

(i) A crew from sub-station travel along the feeder to identify the location of fault and the time taken by the crew is called average fault location identification time.

(ii) Faulted component is isolated by operating the disconnecting switches provided on the feeder.

(iii) The crew will reclose the circuit breaker and tie-line switch to restore the loads under healthy section.

(iv) Faulted component of the feeder is repaired or replaced to restore the loads under faulted section of the feeder.

In the above restoration process (i) the loads in upstream and downstream sides of the feeder are restored after the first three steps and the restoration is said to be due to switching process and the restoration time is equal to the sum of average fault identification time and average switching time. (ii)The load points of the faulted section of the feeder are restored after four steps and the restoration is said to be due to repair or replacement process and the restoration time is equal to the sum of average fault identification time and average repair time. The restoration time due to switching process is less than due to repair process.

Reliability assessment of a distribution system is concerned with the performance of the power supply at the customer load points. The basic parameters used to evaluate the reliability of a distribution system are known as reliability indices [4]. These are average values of a particular reliability characteristic for an entire system or operating region. According to IEEE standards 1366-2003, the reliability indices are categorized as basic load point indices and system performance indices [9]. These indices are normally determined on an annual basis.

The basic load point indices are: (a) average failure rate λ (f/yr), (b) average outage time r (hr) and (c) average annual outage time U (hr/yr). Three basic load point indices are fundamentally important. But, they do not always give a complete representation of the system behavior and response. In order to reflect the severity or significance of a system outage due to sustained faults, additional reliability indices known as system performance indices are used [9]. Some of the system performance indices are: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI) and Energy Not Supplied (ENS). An electrical distribution system with low SAIDI and ENS and with high ASAI is said to be a more reliable system [7, 8].

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The reliability of an electrical distribution system can be improved either by reducing the average failure rate of the components of system or by decreasing the average restoration time after occurrence of a sustained active fault. Fault Passage Indicator (FPI) helps a utility to restore supplies more quickly by reducing the time that an operating crew needs to travel around the network in the search for the fault.

FAULT PASSAGE INDICATORS

A fault passage indicator (FPI) is a device which provides visual or remote indication of a fault on the electric distribution system. FPI will give an indication when fault current passes through its location point. Overhead indicators are used to visualize the occurrence of fault on an overhead electrical system [6]. Some fault passage indicators (FPIs) communicate the information to a central location using radio or cellular signals. A typical fault passage indicator (FPI) is shown in Fig: 1.

Figure 1: Fault passage indicators

TECHNICAL DATA OF FAULT PASSAGE INDICATORS

Working Principle of FPI

FPI looks for a zero sequence current exceeding a specified level and when this current flows for some specified time, it either drops a relay flag or lights a local LED to show the faulty current has gone through this location. Then the operator at the location of FPI starts the process of restoration of both upstream and downstream parts of the feeder

Reasons for Using Fault Passage Indicators (FPI) in Distribution Network

The reasons for using the FPIs in distribution network are given below.

(i) Distance relays give, the distance from the source to a fault, but not which tap the fault is on. FPIs complete the job by pointing the line crew down the correct tap.

(ii) In snowy, icy environments, in heavy forest areas, FPIs with remote displays save time and make life easier for the troubleshooting group.

(iii) Installing FPI at the midpoint of a line allows the crew to restore power to the unaffected portion of the system even before identifying the specific location of the fault.

(iv) FPI allows operators to quickly determine whether a fault occurred on the overhead or underground section of radial line.

FPIs are available with a variety of displays (with and without batteries) and with several trip and reset characteristics, making it easy to select a fault indicator appropriate for most applications.

Apply timed reset FPIs and fault counters in areas affected by brownouts, momentary outages and flickering lights as an efficient means of identifying the location of temporary faults. Using fault passage indicators as preventative tools reduces costs to utilities and their customers, and improves utilities reliability indices. The simplest and most common design of FPI is the earth FPI.

Detection of Steady-State Fault Conditions

On effectively earthed system, the fault current rises in accordance with the frequency of the system and remains flowing until cleared by a circuit breaker in a time scale of, typically, between 50 ms and 500 ms. The current in the circuit rises from the load current to the fault current, and once the fault current is flowing, it is essentially constant. If the fault current exceeds a threshold set in the FPI, then the indicator can be arranged to show that it has seen a fault. However, the load current on the system can vary as customers switch loads ON or OFF. This variation between loads does not happen as quickly as it might rise between load and fault values, and hence, detection of the rate of rise of current is used to improve the sensitivity of the detector.

Resetting the Fault Passage Indictor

The correct operation of a fault passage indicator is to show that a fault current has passed that point on the network and maintain that indication until the operator has learned which indicators have operated. FPIs, therefore, must retain their indicated state for some time, after which they should reset. The reset may be after some period of time, typically three hours, and it is assumed that the operator has read them in this time. However, if the operator has read them in less time, then it would be sensible for the reset to be made. Fig.2 shows the presence of FPIs on a practical 11 kV radial feeder.

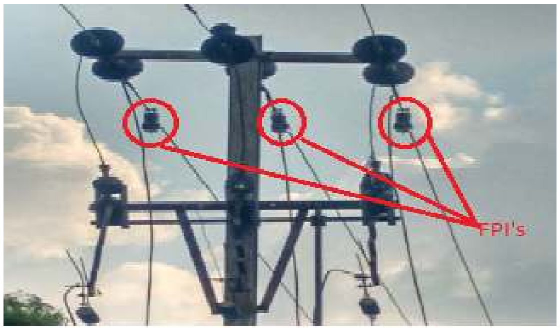

Figure 2: FPIs on a practical 11 kV Radial Feeder

Grading of Fault Passage Indicators

A typical earth fault passage indicator will operate for a zero sequence current of 50 A for 50 ms. The determination of the location of the fault depends solely on seeing which indicators have operated. The indicator farthest away from the source will show the start of the section that contains the fault, but this assumes that every indicator is working correctly and therefore, that an indicator that has not operated because it did not see the passage of fault current rather than the possibility that the indicator was not working correctly at the time of the fault. Care must be taken that, fault passage indicators are tested from time to time to ensure correct operation when required.

Selecting of Fault Passage Indicator

The selection of FPI depends primarily on (i) Type of distribution system such as radial or closed loop (ii) type of neutral earthlings (iii) type of communication channel such as underground system or overhead system and (iv) type of indication required such as earth fault only, phase fault only, or both. There is a wide choice of availability of FPIs for use on open loop effectively earthed systems, which provides either earth fault indication or phase fault indication or both. Some are suitable for overhead systems, whereas others are suitable for underground systems. Some detect the fault current with current transformers, some are mounted directly on the conductor and some are located a meter or away from the conductor and rely on the changing electromagnetic field. The output of the device can be a form of visual indication, whereas others have auxiliary contacts suitable for connecting to a digital input of a remote control RTU.

Indicator

(i) Fault-red flashing LED at 1 second interval. Sensitive EF–red flashing LED 2 at 1 second interval

(ii) Test-both LED's flash at 1 second interval and then steady

(iii) Persistent current above threshold–after 30 seconds, LED's flash alternatively until current ceases.

Remote alarm options: Two output relays, one for fault (alarm 1) and one for persistent current (alarm 2) with selectable operations as follows

(i) Fleeting normally open volt free contacts (0.2 sec),

(ii) Normally open volt free contacts closed during indication period. The contact rating is a 2 A at 30V DC or 0.5 A at 120 V AC.

A radial distribution network with single FPI located at L is shown in Fig.3. FPI will give an indication by dropping a relay flag or lights a local LED, when the fault current passes through the location of FPI.

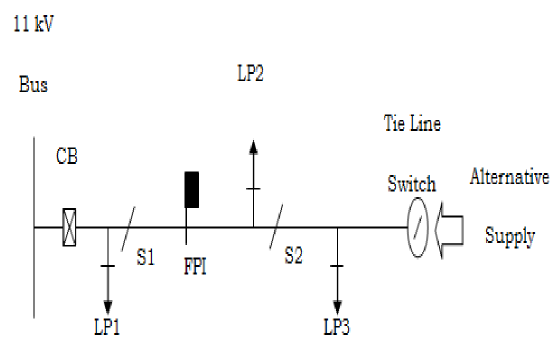

Figure 3: Radial feeders with single FPI

After occurrences of a sustained active fault, circuit breaker of the corresponding feeder will be tripped and the following process is adopted to restore the power. If FPI indicates the fault current either by dropping a relay flag or glowing a local LED, an operator gets information that a sustained fault happened after the location 'L'. Then, operator straight away move towards the location of S1 and open the disconnecting switch S1 and reclose the circuit breaker (CB) to restore the load point LP1 from the main source. Similarly, if operator found a fault between location 'L' and disconnecting switch S2, disconnecting switch S2 is opened and the tie-line switch is closed to restore the load point 3 from the alternate supply. If FPI gives no indication of fault current, the operator open the disconnecting switch S1 and then close normally open tie-line switch to restore the load point 2 and load point 3 from alternate supply. The loads under the faulted sections are restored only after repair or replace of the faulted section. The above restoration process indicates that, FPI helps the utility in finding the location of fault and reduces the average time to find the location of fault and hence, the average restoration time reduces.

MODELING OF RADIAL FEEDER WITH FAULT PASSAGE INDICATORS

The FPI will reduce the average fault location identification time and hence the average restoration time. For example, let consider a feeder of circuit length (L) is 10 kM and a single FPI placed at (L_1) is 4 kM, the remaining part of the feeder length (L_2) is 6 kM as shown in Fig. 3.4. Let the average time for identification of fault location on the feeder (T_0) is 0.75 hr

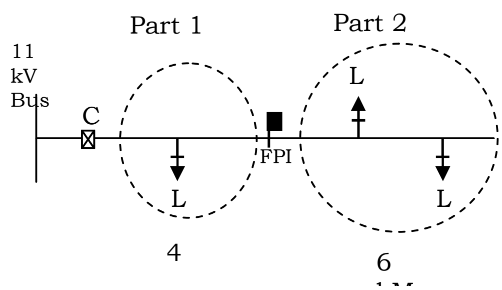

Figure 4: Distribution network with one FPI

When a single FPI is installed, the load points of total feeder are divided into two parts as shown in Fig.4. The load points in between the substation and location of FPI are said to be in Part 1 and the load points between the location of FPI and tie-line switch are said to be in Part 2.

Let,

L= total length of the feeder circuit in kM

L_1= length of Part 1 of the feeder circuit in kM

L_2= length of Part 2 of the feeder circuit in kM

T_0 = Average time of fault location identification (hr), for any location of the fault in a feeder with no FPI.

T_1= Average time of fault location identification (hr) with one FPI, if a fault occurs in Part 1 of the feeder= $T_0 \times [L_1 \div (L1+ L_2)]$ hr

T_2= Average time of fault location identification time (hr) with one FPI, if a fault occurs in Part 2 of the feeder = $T_0 \times [L_2 \div (L1+ L_2)]$ hr.

Since, an operator gets the information of the fault from the FPI; operator can take a decision to restore the power by operating the correct disconnecting switches provided on the feeder. For example, if a sustained fault occurred in Part 1 of the feeder shown in Fig.4,average fault location identification time T_1 = ((0.75)*(4/10)) = 0.3 hour and if a sustained fault occurred in Part 2 of the feeder, the average fault location identification time T_2 = ((0.75)*(6/10)) = 0.475 hour. If restoration is due to due to repair of feeder components or distribution transformers, then the restoration time for part 1 and part 2 are r_1 and r_2 respectively. Where, r_1=repair time+T_1, r_2=repair time+T_2. Otherwise, If restoration is due to switching of feeder sections, r_1=switching time+T_1 and r_2=switching time+T_2

The above analysis indicates that, if path of way of a radial feeder is a in a straight line form and the loads are uniform loads with the same nature, single FPI placed at the middle part of the feeder reduces the fault identification for all parts of the feeder. It is equal to half of that of fault identification time when there is no FPI in the feeder and this location will be the best location. But, in practical distribution systems, the length of radial feeders is very long, with more number of laterals of long length and more of with non-uniform loads, and then operators take more time to identify the location of fault. Therefore to is necessary to determine the best location of single FPI which yields more reliability. In this paper, the best location of FPI is chosen based on one of the important index SAIDI. The location of FPI, which results in minimum SAIDI, is chosen as the best location of FPI. The effect of fault passage indicators on the reliability of a distribution system and the average restoration time can be calculated by using the following algorithm:

(i) Consider each load point on the system

(ii) Consider each failure mode of the load points,

(iii) Calculate average fault location time of the failure mode.

(iv) For each failure mode determine how service can be restored: If service can only be restored by repair, choose the summation of fault location and repair time as restoration time. If service can be restored by switching actions, choose the summation of fault location and switching time as restoration time.

(v) Deduce load point indices by considering all the events leading to failure of the load point and their associated restoration procedures.

(vi) Assess the overall system indices by appropriately combining reliability indices of the load points.

CASE STUDY

In this paper, the configurations of a 2 MVA, 11 kV practical existing radial feeder, based on no. of disconnecting switches on 11 kV feeder sections, availability of no. of alternate supplies & fault passage indicators (FPIs) is shown from Fig.5 to Fig.8 . An attempt is made to determine (i) reliability indices of radial distribution feeder for different configurations given in Table 1, (ii) impact of different locations of single FPI on reliability indices and (iii) optimal location of FPI which yields to minimum SAIDI.

The details of existing feeder are : No. of Circuit breakers (CB)-1,No.of Disconnecting switches on feeder sections-4, No. of Feeder sections-28, No. of fuses in laterals-16,No. of Distribution Transformers (Dtr)- 16,No of Load Points (LP)-16 and No. of Customers-290.Type of Customers are residential, Govt. Institutions and small users. The feeder is operated as radial feeder but connected as a mesh through normally open sectionalizing points. Following a fault on a feeder, the ring main units permit the sectionalizing point to be moved and customers to be supplied from alternative supply points. Operating conditions of radial feeder are: (i)11 kV radial feeder sections and laterals are considered as overhead lines (ii)first order permanent faults due to random outages are considered (iii)protective devices, supply and loads are 100% reliable (iv)normal weather conditions are considered (v)failure events are independent events and (vi)scheduled outages and interaction between the radial feeders are neglected. Feeder section lengths, customer & load data, reliability data and different operating times of a radial feeder are shown in Table 2, Table 3, Table 4 and Table 5 respectively.

Table 1: Different configurations of 11 kV radial feeder

Configuration	No. of Disconnecting Switches	No. of Alternative Supplies	No. of FPIs
A	4	1	0
B	5	2	0
C	4	1	1
D	5	2	1

Table 2: Radial feeder sections length (kM) data

Section	Length	Feeder Section	Failure rate(λ)
1	0.30	15	0.32
2	0.04	16	0.04
3	0.20	17	0.12
4	0.04	18	0.10
5	0.50	19	0.10
6	0.04	20	0.80
7	0.30	21	0.04
8	0.30	22	0.30
9	0.50	23	0.04
10	1.00	24	0.50
11	0.10	25	0.04
12	0.14	26	0.90
13	0.88	27	0.06
14	0.16	28	0.06

Table 3: Customer and average Load (kW) data

Load Point	Avg. Load	No. of Customers	Type of Custumer
1	21.00	1	Govt.Inst,
2	11.25	50	Residential
3	11.25	50	Residential
4	11.25	50	Residential
5	11.25	50	Residential
6	6.75	30	Residential
7	870.	1	Small User
8	56.25	1	Govt.Inst.
9	112.50	1	Govt.Inst.
10	112.50	1	Govt.Inst.
11	450.00	1	Small User
12	11.25	50	Residential
13	21.00	1	Govt.Inst.
14	21.00	1	Govt.Inst.
15	150.00	1	Small User
16	150.00	1	Small User

Table 4: Radial feeder sections failure rate(f/yr) data

Feeder Section	Failure rate(λ) f/yr	Feeder Section	Failure rate(λ)
1	0.0195	15	0.0208
2	0.0026	16	0.0026
3	0.0130	17	0.0078
4	0.0026	18	0.0065
5	0.0325	19	0.0065
6	0.0026	20	0.0520
7	0.0195	21	0.0026
8	0.0195	22	0.0195
9	0.0325	23	0.0026

10	0.0650	24	0.0325
11	0.0065	25	0.0026
12	0.0091	26	0.0585
13	0.0572	27	0.0039
14	0.0104	28	0.0039

Table 5: Different operating times of radial feeder

Sl. No	Average Operating Time for all Load Points	Value (hr)
1	Identification of Fault Location	0.75
2	Operation of Protective Devices	0.25
3	Repair of Feeder Section	4.25
4	Repair of Distribution Transformer	199.25
5	Replacement of Distribution Transformer	9.25
6	Restoration due to Switching Process (1+2)	1
7	Restoration due to Repair of Feeder Section (1+3)	5
8	Restoration due to Repair of DTR (1+4)	200
9	Restoration due to Replacement of DTR (1+5)	10

The system performance indices are calculated using FMEA reliability analysis technique and they are given in next section.

RESULTS

From the reliability point of view, all the feeder sections (28) and all the distribution transformers (16) are connected in series and for the system success all these 34 components must work satisfactorily. Even one component fails, all the load points loses their power supply. FMEA Algorithm is applied to find the effect of sustain fault of each component of feeder on every load point. This effect can be effectively quantified by three basic load point reliability indices and further system performance indices

Table 6: System Performance Indices of Radial Feeder for the Configurations A and B (without FPI)

Configuration	SAIFI	SAIDI	CAIDI	ENS (kWh/yr)	%ASAI
A	0.4226	3.862	9.1363	7821	99.9559
B	0.4226	3.719	8.799	7729	99.9575

Table 7: System performance indices of Radial feeder for different locations of single FPI for Configuration C

Location of FPI	SAIFI	SAIDI	ENS (kWH/yr)	% ASAI
L1	0.4226	3.706	7506	99.9577
L2	0.4226	3.704	7502	99.9577
L3	0.4226	3.708	7511	99.9577
L4	0.4226	3.758	7603	99.9571
L5	0.4226	3.823	7740	99.9564
L6	0.4226	3.850	7804	99.9559
L7	0.4226	3.713	7520	99.9576
L8	0.4226	3.748	7585	99.9572
L9	0.4226	3.857	7807	99.9560

Table 8: System performance indices of Radial feeder for different locations of single FPI for Configuration C

Loc. of FPI	SAIFI	SAIDI	CAIDI	ENS (kWh/yr)	ASAI %
Without FPI	0.423	3.7192	8.799	7729.22	99.9575
L1	0.423	3.5638	8.432	7426.59	99.9593
L2	0.423	3.5578	8.418	7407.41	99.9594
L3	0.423	3.5689	8.444	7451.66	99.9593
L4	0.423	3.6156	8.554	7515.94	99.9587
L5	0.423	3.6808	8.709	7653.18	99.9580
L6	0.423	3.7131	8.785	7718.37	99.9576
L7	0.423	3.5706	8.448	7427.46	99.9592
L8	0.423	3.6144	8.551	7505.47	99.9587
L9	0.423	3.7146	8.789	7717.83	99.9576

Table 9: System Performance Indices of a Radial Feeder For Four Configurations

Configuration	SAIFI	SAIDI	CAIDI	ENS (KWh/y)	%ASAI
A	0.4226	3.862	9.1363	7821	99.9559
B	0.4226	3.719	8.799	7729	99.9575
C	0.4226	3.704	8.763	7502	99.9577
D	0.4226	3.5578	8.418	7407	99.9594

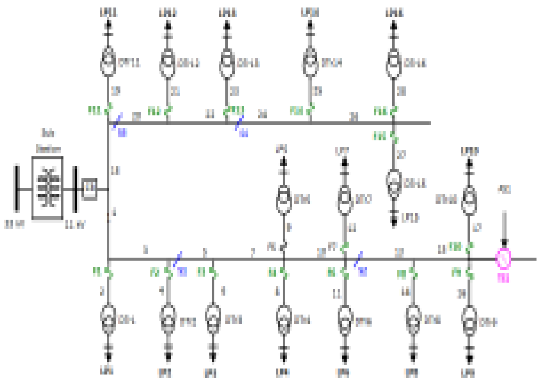

Figure 5: Single line diagram of a radial feeder for Configuration A

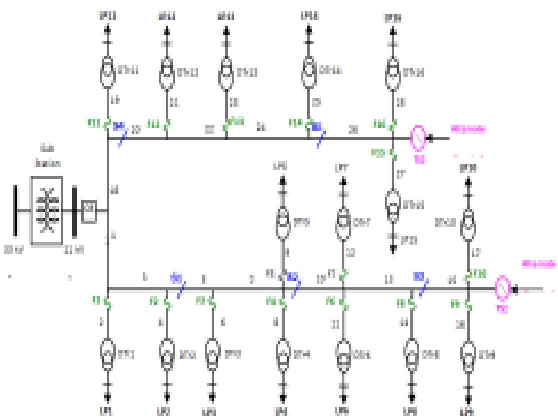

Figure 6: Single line diagram of a Radial feeder for Configuration B

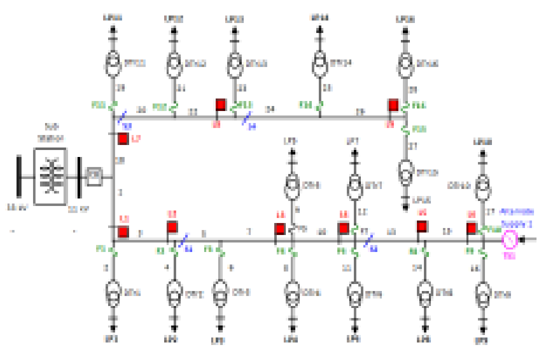

Figure 7: Single line diagram of a Radial feeder for Configuration C

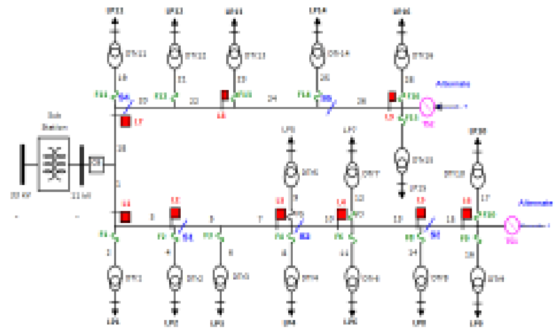

Figure 8: Single line diagram of a Radial Feeder for Configuration D

CONCLUSION

The percentage reduction in SAIDI for the configurations B, C and D with respect to the configuration A is 2.899, 2.902 and 2.941 respectively. Similarly the percentage reduction in ENS for the configuration of B and with best location of single FPI for the configuration of C and D with respect to the configuration A is 1.176, 4.078 and 5.293 respectively. The reliability of feeder is high for Configuration D because of its lesser value of SAIDI and ENS. It indicates that there is considerable increase in reliability of radial feeder with the presence of extra alternate supplies, disconnecting switches and best location of FPI.

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