

# Reliability Enhancement of Radial Distribution System Using Network Reconfiguration

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**Abstract** - Reliability analysis of distribution system ensures the availability of supply at the end of customer terminals. Distribution system is one of the most important part of power system as distribution system is the only link between utility and consumers. During the last few years this area has received great interest. A considerable number of papers have been published describing the development and modelling of distribution system and different techniques to evaluate the reliability indices. This paper describes the network reconfiguration technique to evaluate the reliability indices and to improve them. It also consists the best optimal network configuration that suits for best reliable system. To explain this technique RBTS-6 BUS system is considered from which BUS-2 is chosen for analysis purpose.

**Index terms** - radial distribution system, reliability, network reconfiguration

## I. INTRODUCTION

The distribution system is one of the most important part of power system as it connects the utility with consumers. Most of the distribution systems in practice have a radial configuration so these distribution systems are considered for analysis purpose because of less complexity and easy accessibility. In radial distribution system all components must be operative between load and supply for successful operation of power system. If there is any fault then there will unavailability of supply for the consumers till fault cleared. The reliability of distribution system can be improved by network reconfiguration which can be done by closing normally opened switch (NO) and opening normally closed switches (NC) [1]. Two types of switches are normally used in distribution system that are sectionalizing switch and tie switch. First one is used to disconnect the faulty section from rest of the system and second one is used to restore the system downstream the faulted section from auxiliary supply. This will reduce the fault duration for load points downstream the faulted section [2].

A number of methods have been proposed to solve network reconfiguration to minimize losses, such as integer programming [3] and artificial neural network [4] and simulated annealing [5]. Other constraints may be taken into account, for example load balancing [5], introduction of distributed generation [6].

Tsai, L. H. presented a model for improving the reliability of electric distribution systems through network reconfiguration. Two main reliability indices are targeted to be minimized: system average interruption frequency (SAIFI) and the system average interruption duration (SAIDI). The mathematical formulations for calculating the change of SAIDI and SAIFI as a result of reconfiguration were developed to identify beneficial load transfers. However, his method did not take into account reliability worth, which can be described in terms of customer interruption costs.

Ye Bin et. al proposed network reconfiguration to increase reliability worth by an improved genetic algorithm. The mathematical model is formulated in which its objective function is to minimize customer interruption costs. The procedure was illustrated by the distribution system connected at bus 2 of the 6-bus Roy Billiton Test System (RBTS). It is shown from their studies that their developed methodology permits flexible use of sectionalizing and tie switches without introducing additional costs while being able to achieve large possible economic benefit

The emphasis in this paper is given on SAIFI, SAIDI, ASUI, ASAI and CAIDI. All these are reliability indices for distribution system. All these parameters are calculated for different configurations of BUS-2. Five cases are created and the best optimal solution of network configuration is obtained. The purpose of this paper is to extend the RBTS to include distribution systems that contain the main elements found in practical systems but which are sufficiently small that they can be easily analyzed using hand calculations. The paper contains all the basic data needed to perform continuity analyses together with limited load flow data so that some design studies containing load flow solutions are also possible. The paper also contains basic results of continuity studies for a range of sensitivity studies and alternative design/operating configurations.

## II. DESCRIPTION OF THE DISTRIBUTION NETWORK

The RBTS has 5 bus bars (BUS2- BUS6) from which BUS2 is selected for analysis purpose. BUS2 have generation associated with it so effect of generation and transmission on all load points can also be seen. All details of customer type and load is given in table

TABLE 1. PEAK LOAD IN THE RBTS BUS 2

Customer type	Peak load, MW
RESIDENTIAL	7.25
SMALL USERS	3.50
GOVERNMENT/ INSTITUTION	5.55

COMMERCIAL	3.70
TOTAL	20

TABLE 2. FEEDER TYPE AND LENGTHS (BUS 2)

Feeder type	Length(KM)	Feeder section numbers
1	0.60	2 6 10 14 17 21 25 28 30 34
2	0.75	1 4 7 9 12 16 19 22 24 27 29 32 35
3	0.80	3 5 8 11 13 15 18 20 23 26 31 33 36

TABLE 3. CUSTOMER DATA

Number of load points	Load points	Customer type	Load level per load point, MW		Number of customers
			average	peak	
<b>BUS 2</b>					
5	1-3, 10, 11	Residential	0.535	0.8668	210
4	12, 17-19	Residential	0.450	0.7291	210
1	8	Small users	1.00	1.6279	1
1	9	Small users	1.15	1.8721	1
6	4,5,13,14,20,21	Govt./Inst.	0.566	0.9167	1
5	6,7,15,16,22	Commercial	0.454	0.7500	10

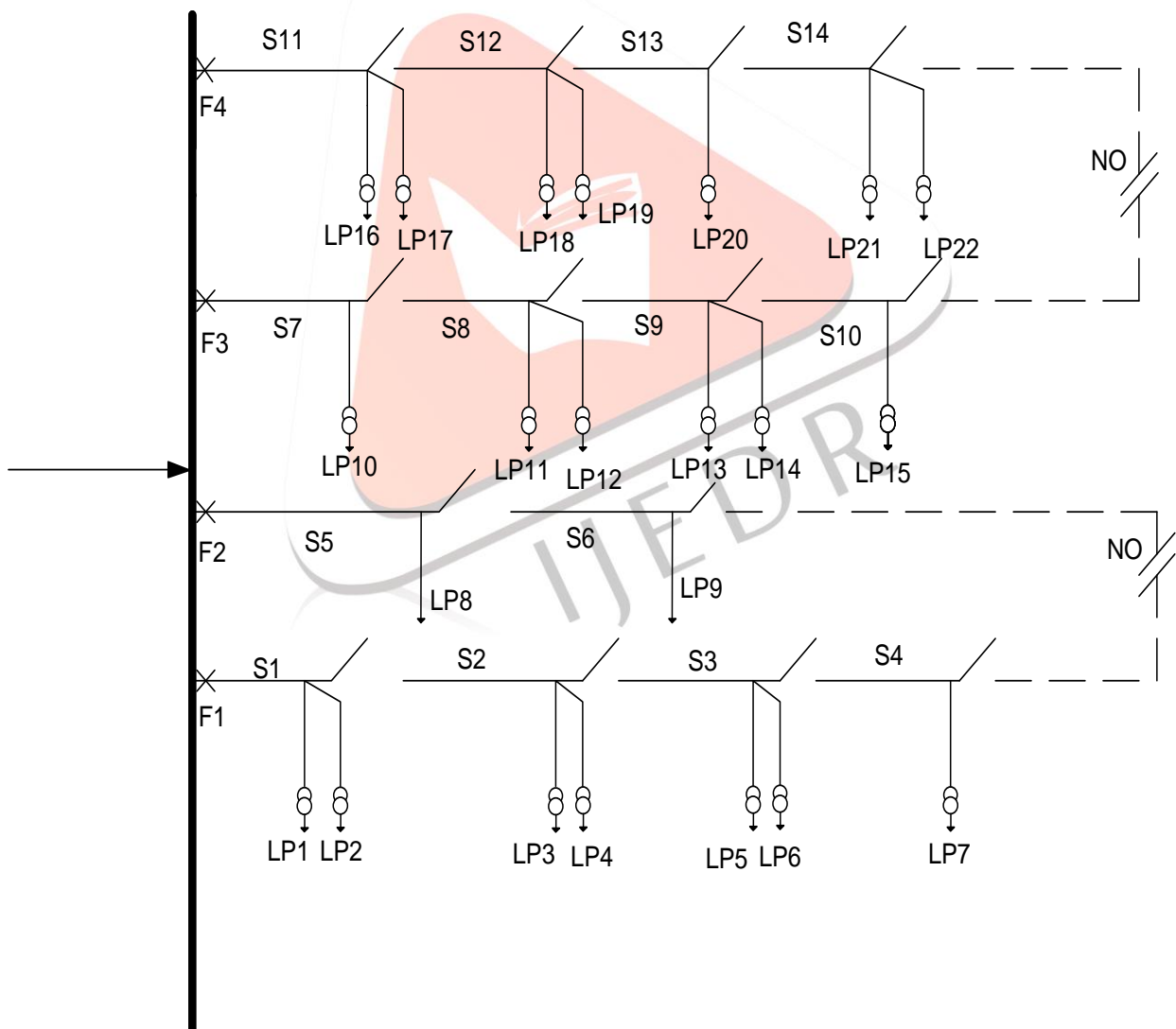


FIGURE 1. DISTRIBUTION SYSTEM FOR RBTS BUS 2

These assumptions are made for the above distribution system.

- a) Residential, commercial and government/institution loads are metered on the low voltage side and the transformer is utility property and included in the analysis. The small user loads are metered on the high voltage side and the transformer is customer property and not included.

- b) The feeders are operated as radial feeders 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.
- c) The loading level of BUS2 (20MW) only justifies a single supply point.
- d) All breakers in the system are identified and considered as 100% reliable.
- e) All the 11kv and laterals are considered as overhead lines.

In table 3 all details about the customer type, average load, peak load and number of customers connected with each load point is given. With the help of this customer data, we can obtain all feeder data and can obtain the reliability of the system and this loading data is shown in table 4.

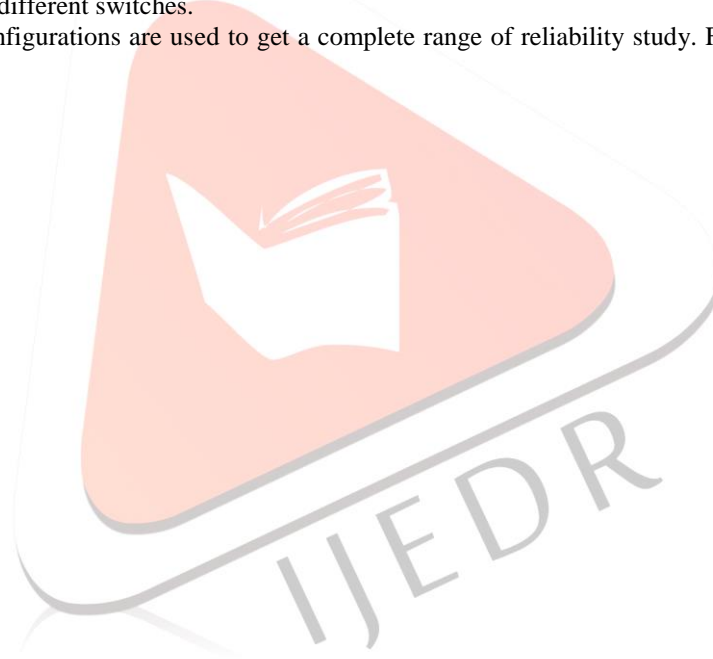
TABLE 4. LOADING DATA OF FEEDER

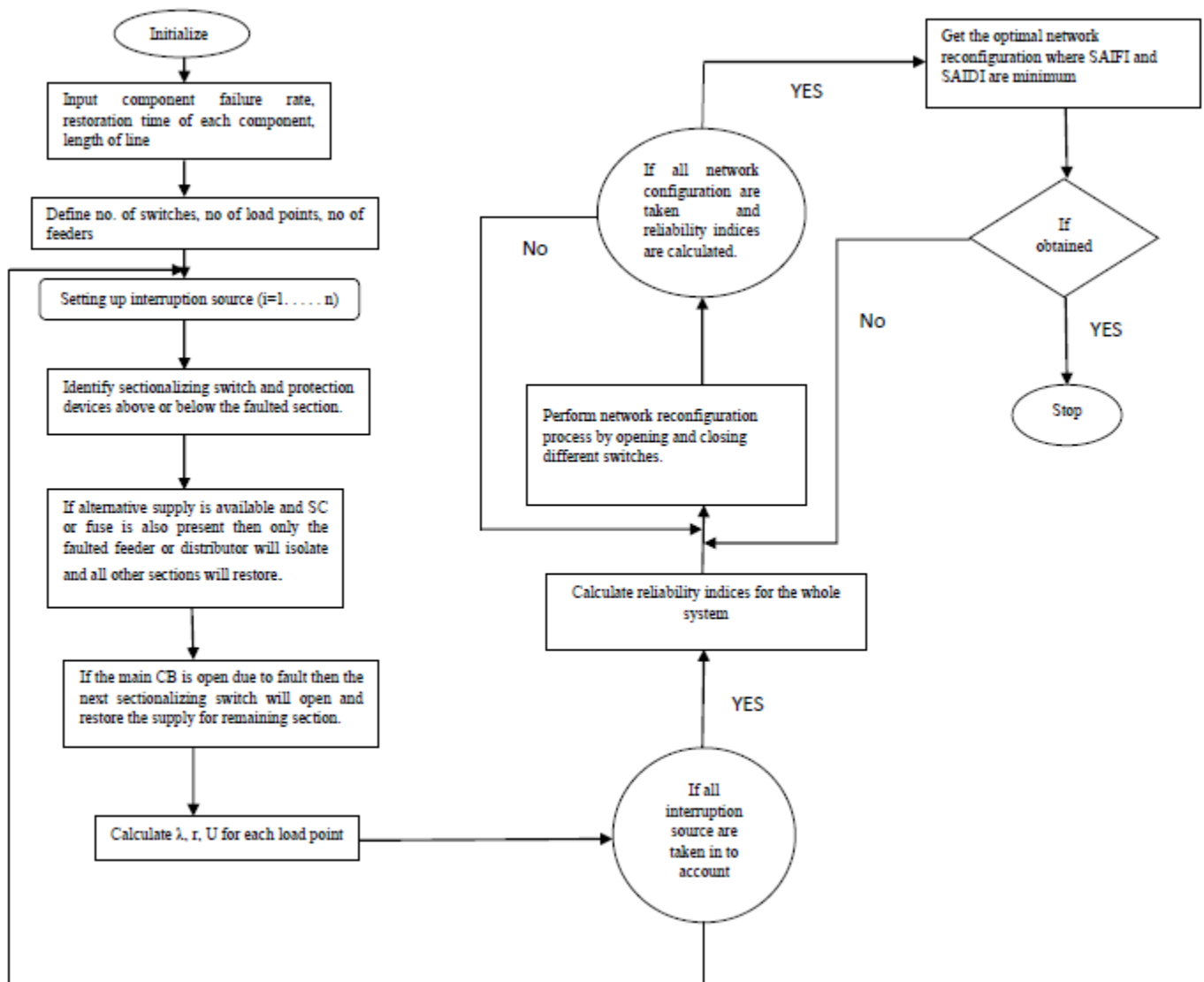
Feeder number	Load points	Feeder load, MW		Number of customers
		average	peak	
<b><i>BUS 2</i></b>				
F1	1-7	3.645	5.934	652
F2	8-9	2.15	3.500	2
F3	10-15	3.106	5.057	632
F4	16-22	3.390	5.509	622
<b>BUS 2 total</b>		<b>12.291</b>	<b>20</b>	<b>1908</b>

### III. NETWORK RECONFIGURATION TECHNIQUE

As shown in above figure, the distribution network consists of 4 feeder with 22 total load points and 2 tie switches that are normally open switch and 14 sectionalizing switch. In this network various configurations of network can be designed by changing the opening and closing sequence of different switches.

Here in this paper 5 different configurations are used to get a complete range of reliability study. For this purpose the following sequence of steps is used.





**FLOW CHART FOR NETWORK RECONFIGURATION TECHNIQUE**

In this paper 5 cases are examined and reliability parameters named SAIFI, SAIDI, CAIDI, ASAI and ASUI are calculated for all these 5 cases. To calculate all these parameters we need some basic load point indices and these are failure/ year ( $\lambda$ ), repair hours ( $r$ ) and hours/ year ( $U$ ). All these parameters for all cases all shown in this paper and finally comparison between all cases is given.

Basic system and reliability data that uses in this paper is given below.

TABLE 5. SYSTEM AND RELIABILITY DATA

Component	$\lambda$ (failure/year)	$r$ (hrs)	$S$ (hrs)	$r_p$ (hrs)
Line (11kv)	0.065	5	1	-
Transformer (11/0.415 KV)	0.015	200	1	5

S= switching time (hrs)  
 $r_p$ = replacement time (hrs)  
 $r$  = repair time (hrs)

**IV. RESULT ANALYSIS FOR RBTS BUS2 USING NETWORK RECONFIGURATION**

All the data given in above tables, can be utilizes to calculate the reliability indices for each feeder. In this analysis firstly the base case is considered in which system have disconnects- fuse- alternate supply- replacement of transformer. All results for base case are shown in table 6. For all other cases results are shown in table 7.

Assumptions:

- 1) All the fuse and circuit breakers in the system are 100% reliable.
- 2) All switches operates successfully whenever they required to operate.

TABLE 6. BASE CASE (disconnects- fuse- alternate supply- replacement of transformer)

Load point	Load point indices			Load point	Load point indices		
	$\lambda$	$r$	$U$		$A$	$r$	$U$
LP1	0.24	2.71	0.65	LP12	0.256	2.86	0.731
LP2	0.253	2.83	0.715	LP13	0.253	2.62	0.663
LP3	0.253	2.83	0.715	LP14	0.256	2.65	0.68
LP4	0.24	2.71	0.65	LP15	0.243	2.7	0.654
LP5	0.253	2.83	0.715	LP16	0.253	2.82	0.715
LP6	0.25	2.8	0.7	LP17	0.243	2.74	0.67
LP7	0.253	2.83	0.715	LP18	0.243	2.7	0.653
LP8	0.140	3.89	0.54	LP19	0.256	2.8	0.718
LP9	0.140	3.60	0.50	LP20	0.256	2.8	0.718
LP10	0.243	2.7	0.654	LP21	0.253	2.62	0.663
LP11	0.253	2.82	0.715	LP22	0.256	2.8	0.718

SAIFI =  $\sum (\lambda_i * N_i) / N_t$  (system average interruption frequency index)

SAIDI =  $\sum (U_i * N_i) / N_t$  (system average interruption duration index)

CAIDI =  $\frac{SAIDI}{SAIFI}$  (customer average interruption duration index)

ASAI =  $1 - \frac{SAIDI}{8760}$  (average service availability index)

ASUI =  $1 - ASAI$  (average service unavailability index)

These are some of the reliability that are calculated in this paper. These parameters are calculated for all 5 cases 3 and the final result is shown in the following table.

TABLE 7. EFFECT OF RECONFIGURATION OF RBTS 2 BUS SYSTEM ON SAIFI, SAIDI AND CAIDI

CASE (System parameters)	SAIFI	SAIDI	CAIDI	ASAI	ASUI
Base case as per RBTS	0.248	0.6916	2.788	0.999921	0.000079
When LP <sub>7</sub> is shifted to feeder 2 and NO switch is closed and sectionalizing switch S <sub>4</sub> is opened. F <sub>3</sub> and F <sub>4</sub> remains unchanged.	0.234	0.678	2.89	0.999922	0.000078
When both NO open switch are closed and LP <sub>7</sub> is shifted in feeder 2 and LP <sub>15</sub> in feeder 4	0.2347	0.670	2.855	0.999923	0.000077
When LP <sub>5</sub> , LP <sub>6</sub> and LP <sub>7</sub> are shifted to feeder 2 by closing the NO switch and feeder 3 and feeder 4 are same as base case	0.219	0.663	3.02	0.999924	0.000076
When both NO switch are closed. LP <sub>5</sub> , LP <sub>6</sub> and LP <sub>7</sub> are shifted to feeder 2 and LP <sub>15</sub> to feeder 4.	0.219	0.655	3.0	0.999925	0.000075

## V. CONCLUSION

This paper has presented a meaningful analysis of RBTS BUS2 system using network reconfiguration technique and from the results obtained, we can see that the CASE 5 (when both NO switch are closed and LP<sub>5</sub>, LP<sub>6</sub>, LP<sub>7</sub> are shifted to feeder 2 and LP<sub>15</sub> is shifted to feeder 4) is the best optimal network reconfiguration among the all other cases.

According to this paper we can analyze that an improvement of 11.6% is obtained in SAIFI and an improvement of 5.29% is obtained in SAIDI because of this network reconfiguration technique. This technique can also be used in cost worth analysis of distribution system where EENS and ECOST are calculated for network for each configuration to justify that each dollar is used at proper place to improve the reliability of system, but this is not the scope of this paper. Finally the conclusion of this paper is that by network reconfiguration technique, reliability indices of the radial distribution system can be improved.

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## APPENDIX:-

TABLE 8. WHEN LOAD POINT 7 IS SHIFTED TO FEEDER 2 AND FEEDER 3 AND FEEDER 4 REMAINS SAME AS BASE CASE.

Load point	Load point indices			Load point	Load point indices		
	$\lambda$	$r$	$U$		$\lambda$	$r$	$U$
LP1	0.200	3.052	0.611	LP12	0.256	2.86	0.731
LP2	0.213	3.171	0.676	LP13	0.253	2.62	0.663
LP3	0.213	3.171	0.676	LP14	0.256	2.65	0.68
LP4	0.200	3.052	0.611	LP15	0.243	2.7	0.654
LP5	0.213	3.171	0.676	LP16	0.253	2.82	0.715
LP6	0.21	3.14	0.66	LP17	0.243	2.74	0.67
LP7	0.19375	3.188	0.61775	LP18	0.243	2.7	0.653
LP8	0.17875	3.2545	0.58175	LP19	0.256	2.8	0.718
LP9	0.17875	3.0363	0.54275	LP20	0.256	2.8	0.718
LP10	0.243	2.7	0.654	LP21	0.253	2.62	0.663
LP11	0.253	2.82	0.715	LP22	0.256	2.8	0.718

TABLE 9. WHEN BOTH NO OPEN SWITCH ARE CLOSED AND LOAD POINT 15 IS CONNECTED WITH FEEDER 4 AND LOAD POINT 7 IS CONNCEVTD WITH FEEDER 2

Load point	Load point indices			Load point	Load point indices		
	$\lambda$	$r$	$U$		$\lambda$	$r$	$U$
LP1	0.200	3.052	0.611	LP12	0.20675	2.972	0.6145
LP2	0.213	3.171	0.676	LP13	0.2035	3.02	0.6145
LP3	0.213	3.171	0.676	LP14	0.208	3.04	0.631
LP4	0.200	3.052	0.611	LP15	0.291	3.101	0.702
LP5	0.213	3.171	0.676	LP16	0.301	2.538	0.764
LP6	0.21	3.14	0.66	LP17	0.291	2.458	0.715
LP7	0.19375	3.188	0.61775	LP18	0.291	2.41	0.702
LP8	0.17875	3.2545	0.58175	LP19	0.304	2.524	0.767
LP9	0.17875	3.0363	0.54275	LP20	3.04	2.524	0.76725
LP10	0.19375	3.12	0.60475	LP21	0.301	2.365	0.712
LP11	0.2035	3.275	0.667	LP22	0.304	2.395	0.728

TABLE 10 WHEN SWITCH 3 -4 ARE OPEN AND LOAD POINT 5,6,7 ARE SHIFTED TO FEEDER 2 AND FEEDER 3 AND FEEDER 4 REMAINS SAME AS BASE CASE

Load point	Load point indices			Load point	Load point indices		
	$\lambda$	$r$	$U$		$\lambda$	$r$	$U$
LP1	0.1515	3.71	0.5625	LP12	0.256	2.86	0.731
LP2	0.1645	3.81	0.6275	LP13	0.253	2.62	0.663
LP3	0.1645	3.81	0.6275	LP14	0.256	2.65	0.68
LP4	0.1515	3.71	0.5625	LP15	0.243	2.7	0.654
LP5	0.2425	2.91	0.7055	LP16	0.253	2.82	0.715
LP6	0.24	2.87	0.689	LP17	0.243	2.74	0.67
LP7	0.2425	2.75	0.6665	LP18	0.243	2.7	0.653
LP8	0.2425	2.91	0.7055	LP19	0.256	2.8	0.718
LP9	0.2425	2.75	0.6665	LP20	0.256	2.8	0.718
LP10	0.243	2.7	0.654	LP21	0.253	2.62	0.663
LP11	0.253	2.82	0.715	LP22	0.256	2.8	0.718

CASE 5 WHEN SWITCH 3 IS ALSO OPENED AND ALL 3 LOAD POINT (5, 6, and 7) ARE CONNECTED WITH FEEDER 2 AND LOAD POINT 15 IS CONNECTED WITH FEEDER 4.

<i>Load point</i>	<i>Load point indices</i>			<i>Load point</i>	<i>Load point indices</i>		
	$\lambda$	$r$	$U$		$\lambda$	$r$	$U$
<b>LP1</b>	0.1515	3.71	0.5625	<b>LP12</b>	0.20675	2.972	0.6145
<b>LP2</b>	0.1645	3.81	0.6275	<b>LP13</b>	0.2035	3.02	0.6145
<b>LP3</b>	0.1645	3.81	0.6275	<b>LP14</b>	0.208	3.04	0.631
<b>LP4</b>	0.1515	3.71	0.5625	<b>LP15</b>	0.291	3.101	0.702
<b>LP5</b>	0.2425	2.91	0.7055	<b>LP16</b>	0.301	2.538	0.764
<b>LP6</b>	0.24	2.87	0.689	<b>LP17</b>	0.291	2.458	0.715
<b>LP7</b>	0.2425	2.75	0.6665	<b>LP18</b>	0.291	2.41	0.702
<b>LP8</b>	0.2425	2.91	0.7055	<b>LP19</b>	0.304	2.524	0.767
<b>LP9</b>	0.2425	2.75	0.6665	<b>LP20</b>	3.04	2.524	0.76725
<b>LP10</b>	0.19375	3.12	0.60475	<b>LP21</b>	0.301	2.365	0.712
<b>LP11</b>	0.2035	3.275	0.667	<b>LP22</b>	0.304	2.395	0.728

