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NEW RECLOSER CHARACTERISTIC TO IMPROVE FUSE SAVING IN DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION

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Key words: Distribution network, Distributed generation, Fuse saving, Microprocessor-based recloser.

Incorporating distributed generation (DG) into distribution networks could lead to nuisance fuse blowing because of miscoordination between recloser and fuse. This paper presents a new non-standard characteristic for microprocessor-based recloser to improve fuse saving strategy in distribution networks with/without DG. The proposed scheme uses only local measurements of the three phase voltage and current magnitudes, thereby obviating the need for communication links between the recloser and DG units. The new characteristic is self-adaptive, i.e. it changes the operating time of the recloser in response to fault conditions to maintain adequate grading margin with downstream fuses. The new recloser characteristic is tested by simulation study for an Iranian practical distribution network. In addition to the test cases with high penetration levels of DG, the absence of DG in the distribution network is also analysed on the recloser-fuse grading time margin. The test results validate the performance of the new recloser characteristic under different fault conditions. The comparative results show considerable improvement over the previously proposed methods in the literature.

1. INTRODUCTION

Fuses are the main protective device in most conventional distribution networks (DNs). In general, fuses are located at head of laterals for overcurrent protection. On the other hand, almost 70% to 80% of faults on overhead distribution circuits have transient nature [1] where fuse saving strategy should be employed to reduce customer outage time and to improve customer reliability indices. Many utilities place a recloser at main feeders and use fuse-saving coordination with downstream fuses to save fuse under transient faults.

Despite the obvious benefits of integrating DG into DNs, it causes some serious challenges, mainly in the network protection. In the context of recloser-fuse coordination, presence of DG could lead to undue fuse operation during transient faults, hence increased customer interruption duration.

DG changes fault level in DNs; it could decrease fault current at the head of a feeder and increase it at faulted section in contrast to the fault behavior in conventional DNs without DG. When the fault current in the faulted section with fuse is more than the fault current that passes through the recloser, it may lead to the fuse operation before fast operation of the recloser. Therefore, in such cases fuse-saving strategy is broken. Several methods have been proposed in the literature for observing the fuse-saving strategy in the DNs with DG. One method is to disconnect all DG units before any chance for the fuse to blow up [2]. This method requires a very fast disconnection of the DG, even under transient faults.

Methods in [3–5] utilise ratio of recloser current and fuse current ($I_{recloser}/I_{fuse}$) to modify time dial setting (TDS) of fast operation of the recloser. $I_{recloser}/I_{fuse}$ varies by changing the DG location and/or DG capacity or DN configuration. Therefore, this method needs various measurement points in DN, at least equal to the number of fuses, and communication links between measurement points and control center that these additions come at a high capital cost. On the other hand, ignoring fuse saving strategy could lead to increased outages caused by transient faults.

In [6–8], the maximum DG capacity at each possible or optimum location is found to prevent the recloser-fuse miscoordination without any changes in the protection settings. However, when it is required to increase threshold levels of the DG capacity, the coordination between recloser and fuse can be lost.

In order to overcome recloser-fuse miscoordination, use of fault current limiter (FCL), or superconductive FCL (SFCL) is proposed in [9–13]. The optimum FCL impedance and location must be changed during DN reconfiguration or change of location and capacity of DG. Therefore, the optimum size and location of FCL can be a new challenge.

According to [1] to ensure proper recloser-fuse coordination, recloser must be equipped with both time and instantaneous overcurrent elements. The current setting of the instantaneous element must be adaptively changed according to location and capacity of the DG.

This paper proposes a new scheme based on non-standard inverse time characteristic (NSITC) for microprocessor-based recloser that depends on faulted phase current and voltage magnitude for determining the operating time of the recloser. The proposed scheme uses magnitude of voltage that is available with directional overcurrent element, or from the substation voltage transformer if the recloser is installed at the head of the feeder. The proposed method does not require any communication link between the recloser and DG units or the feeder measurement points. The performance of the proposed recloser characteristic is evaluated by simulation study of two Iranian practical distribution networks without and with high penetration levels of DG for various fault locations. It is shown that the proposed characteristic can overcome shortcomings of the previously proposed methods for the fuse-saving strategy.

The rest of this paper is organized as follows: Section 2 presents a review of DN protection devices and their coordination. Section 3 describes the proposed non-standard inverse time characteristic. Details of two Iranian practical distribution networks are presented in Section 4. Sections 5 presents simulation results and discussion. Finally, the conclusion is drawn in Section 6.

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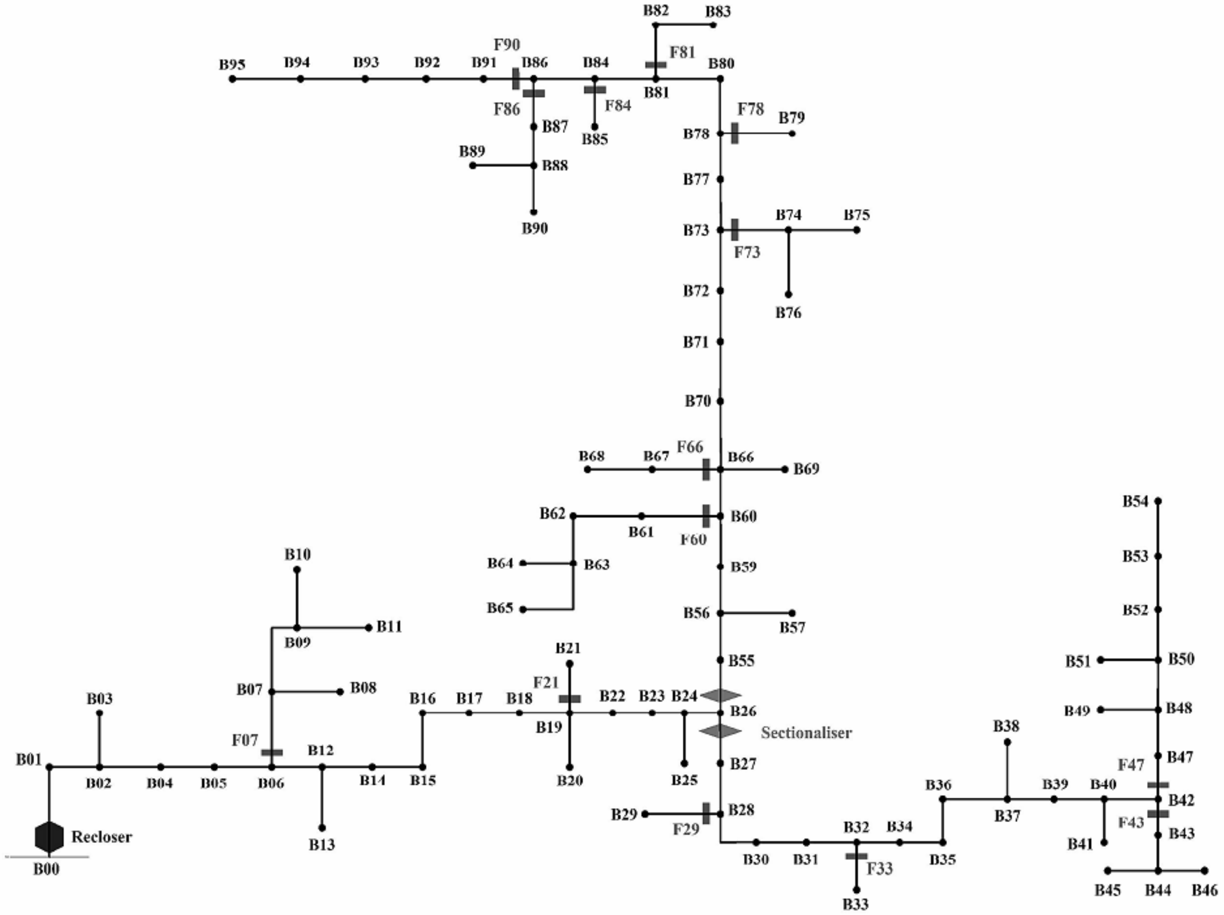

Fig. 1 – An Iranian practical distribution network.

2. PROTECTION COORDINATION IN DISTRIBUTION NETWORKS

Several protection devices are use in DNs including overcurrent relays, reclosers, sectionalisers, and fuses. Proper coordination between various devices is necessary to reduce the fault outage area, duration of customer interruptions and equipment damage.

Figure 1 shows an Iranian practical DN with recloser, sectionalisers, and fuses. A recloser is located at the head of the main feeder, two sectionalisers on the main feeder and fuses on the laterals. When a fault occurs downstream of the sectionaliser, after a predefined number of the recloser operations and while the feeder is de-energised, the sectionaliser operates to clear permanent fault. This allows the recloser to energise non-faulted areas at the upstream of the sectionaliser. If the fault is transient or cleared by fuse operation, the operating mechanism of the sectionaliser is reset. Fuses and sectionalisers should be coordinated with the recloser. Fuse must operate only for a permanent fault on the its lateral. In case of transient fault before fuse operation, fast operation of the recloser de-energises the feeder in order to give the fault a chance to be cleared.

2.1. PROTECTION DEVICES MODEL

Every fuse and recloser has an inverse current-time characteristic. Typically, traditional reclosers use extremely inverse time characteristic for their overcurrent element to provide good coordination with fuses [6]. The extremely inverse time-current characteristic is expressed as [14]:

$$t_{recl} = [\frac{28.2}{\left(\frac{I_{sc}}{I_{set}}\right)^2 - 1} + 0.1217] \times \text{TDS}, \tag{1}$$

where TDS is time dial setting in fast or slow mode, I_{sc} is the fault current passing through the recloser, I_{set} is the relay current setting, t_{recl} is the operating time of the recloser relay.

Fuse current-time characteristic can be described by the following equation:

$$\log\left(t_{fuse}\right) = a \times \log\left(I_{fuse-sc}\right) + b, \tag{2}$$

where a and b are constant parameters, $I_{fuse-sc}$ is the fault current passing through the fuse, and t_{fuse} is the fuse operating time.

The constant a is the slope of the straight line on I^2t log–log graph. It is practically accepted that all the fuses in a DN have the same constant a [6]. In order to calculate the constant b, first a three phase fault is applied at the end of the protected lateral and the fault current of the fuse and the recloser is calculated. Then, the fuse operating time is computed using [6]:

$$t_{fuse} = t_{f-recl} + \frac{\left(t_{s-recl} - t_{f-recl}\right)}{2}, \tag{3}$$

where t_{f-recl} and t_{s-recl} are the recloser operating times in fast and slow modes, respectively, obtained using equation (1). The constant b is obtained using equations (3) and (2).

3. PROPOSED RELAY CHARACTERISTICS

The advent of microprocessor-based relays has created the facility to apply user-defined and non-standard relay characteristics. In [15–19] non-standard relay characteristics are used for protection of DNs with DG units. These methods are intended to decrease the overall tripping time in the protection coordination problem of DNs.

This paper proposes a new non-standard inverse time characteristic for the fast operation curve of reclosers, which automatically modifies recloser operating time of the fast modes and increases time margin between fuse and recloser operating times. The new relay characteristic overcomes the shortcomings of the previous methods to render a simple and reliable fuse-saving strategy.

The proposed NSITC utilises the phase fault voltage magnitude in addition to the fault current magnitude at the recloser location as given by:

$$t_{precl} = \frac{80}{\left(\frac{Z_{set}}{Z_{sc}}\right)^2 - 1} \times e^{(-k \times Vsc)} \times \text{TDS}, \quad (4)$$

where t_{precl} is the recloser operating time and k is constant parameters, Z_{set} and Z_{sc} are the setting and short circuit impedance seen by recloser that are given by:

$$Z_{set} = \frac{V_{set}}{I_{set}}, \quad (5)$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}}, \quad (6)$$

where V_{sc} is phase fault voltage magnitude measured at the recloser location in volt, and V_{set} is the voltage setting in volt.

When a fault occurs, the proposed characteristic in equation (4) improves the performance of the recloser fast operation depending on the fault location (by using the voltage magnitude at the recloser location).

The proposed characteristic provides recloser-fuse coordination against all fault types including phase to phase faults and single or double phase to earth faults. For different fault types, the value for constant k in equation (4) should be set according to the fault type; hence a fault classification is required before using the characteristic.

During a fault, the three phase voltage and current magnitudes, i.e. V_{sc}, I_{sc},, are measured at the recloser location. Then, by using equation (4), the operating time for each phase is calculated and the minimum time is used as the overall operating time of the fast operation of the recloser.

4. TEST SYSTEM

4.1. DISTRIBUTION NETWORK

In order to illustrate the effectiveness of the proposed scheme for the fuse-saving strategy, the data is employed from an Iranian 20 kV practical distribution network, which is shown in Fig. 1. The network contains 14 fuses and is energised by two 63/20 kV, 30 MVA power transformers with 13.7 % transient reactance. Fault current at the 63 kV busbar is 3.65 kA. Detailed information of the network is given in Table A.1 in Appendix.

4.2. DISTRIBUTED GENERATORS

For the fuse-saving study, synchronous type of DG is usually used as they have a high contribution to fault currents that may reach up to 10 per unit (p.u.) of the rated current [6].

In this paper, each synchronous generator has a capacity of 1.3 MVA and a subtransient impedance of 13.6 %. The generators are connected to the DN through a 0.4/20 kV step-up transformer with 3 % transient reactance.

4.3. FUSE MODELLING

The method explained in Section 2.1 is used to model the fuses. The constant a in the inverse-time overcurrent characteristic of the fuse is set to –1.8 [6]. TDSs of the recloser characteristic for the slow and fast operation times are set to 1.5 and 0.5, respectively [6].

The values of the constant b for all the fuses in the DN are given in Table 1. The fuse name is in accordance with the line name at which it is installed.

Table 1

Constant *b* of DN fuses

Fuse name	constant *b*	Fuse name	constant *b*
F07	5.750	F66	5.665
F21	5.707	F73	5.655
F29	5.679	F78	5.649
F33	5.661	F81	5.649
F43	5.635	F84	5.644
F47	5.634	F86	5.639
F60	5.668	F90	5.641

5. SIMULATION STUDY AND DISCUSSION

5.1. PROPOSED NSITC SETTINGS

The settings of the proposed NSTIC are calculated by assuming there is no DG connected initially. It is required that the recloser to be equipped with directional element and can measure phase voltage magnitude.

I_{set} is calculated as follows:

$$I_{set} = I_{maxload} \times \text{OLF}, \quad (7)$$

where $I_{maxload}$ is the maximum load current that passes through the recloser and OLF is the overload factor that is set to 1.5 [6].

For the test network $I_{maxload}$ is 162.77 A. Therefore, according to equation (7) I_{set} for the recloser at DN is set at 244.2 A. For the recloser the V_{set} is set to 1 p.u., and TDS is set to 1.

The k constant in equation (4) for three-phase (L.L.L) faults, two-phase faults (L.L or L.L to earth (L.L.G)) and single-phase to earth (L.G) faults is set to 2, 2.5, and 3.25, respectively. The coordination time interval (CTI) is the minimum interval time between the fast operation of the recloser and the fuse, which is considered to be 0.1 s [6].

5.2. PROTECTION COORDINATION ASSESSMENT

Two scenarios are created for the network configuration. In the first scenario no DG is connected to the DN, and in the second scenario high DG penetration is considered by integrating DG units at different points of the DN.

The DG connection points are B26, B42 and B73 in the DN. Two generator units are installed at B42 and B73 and one generator unit is installed at B26. Each generator unit produces 1 MW active power and its operating power factor is set to 0.95. In order to incorporate a real condition for recloser-fuse coordination, the operation limits are considered in selection of the DG connection points and number of the DG generator units.

In order to evaluate performance of the proposed scheme in the two scenarios, a fault is applied just at the downstream of each fuse to calculate the maximum fault current the passes through each fuse. In the first scenario, the recloser operating time of the proposed NSITC, t_p, is compared with the recloser operating time of the standard characteristic. In the second scenario, proper coordination cannot be obtained using the conventional characteristic for the recloser, hence t_p is compared with the proposed method in [3].

The results of the first scenario for L.L.L faults are given in Table 2, in which the first column is referred to the lines at which the fuses are installed, t_s is referred to the recloser operating time of the standard characteristic, CTI$_p$ and CTI$_s$ are coordination time interval between recloser and fuse operating time obtained using the proposed and the standard characteristics, respectively.

According to Table 2, the operation time of the recloser using the standard characteristic and the proposed NSITC are close to each other in the absence of DG. The maximum and average difference time between CTI$_s$ and CTI$_p$ in the absence of DG are 0.171 and 0.142 seconds, respectively.

Table 2

Results of recloser-fuse coordination
on DN under L.L.L fault, without DG

Fuse line	I_{recl} (A)	I_{fuse} (A)	V_{sc} (p.u.)	t_f (s)	t_s (s)	t_p (s)	CTI$_s$ (s)	CTI$_p$ (s)
L07	3120	3078	0.532	0.296	0.148	0.048	0.248	0.148
L21	2525	2505	0.616	0.388	0.194	0.083	0.305	0.194
L29	2163	2134	0.676	0.486	0.243	0.121	0.365	0.243
L33	1925	1886	0.717	0.582	0.291	0.159	0.423	0.291
L43	1499	1441	0.785	0.890	0.445	0.276	0.614	0.445
L47	1475	1415	0.789	0.918	0.458	0.287	0.631	0.460
L60	1994	1962	0.702	0.551	0.275	0.146	0.405	0.276
L66	1935	1902	0.710	0.579	0.289	0.156	0.423	0.290
L73	1797	1757	0.733	0.652	0.326	0.185	0.467	0.326
L78	1712	1667	0.747	0.707	0.354	0.206	0.501	0.353
L81	1711	1667	0.746	0.707	0.354	0.206	0.501	0.353
L84	1632	1582	0.760	0.768	0.384	0.229	0.539	0.384
L86	1561	1507	0.771	0.829	0.415	0.253	0.576	0.414
L90	1579	1527	0.767	0.813	0.406	0.246	0.567	0.407

The results of the second scenario for L.L.L and L.L faults are given in Table 3. The results for L.L.G and L.G faults are given in Table 4; t_r in Tables 3 and 4 is the recloser operating time by using method in [3]. In the second scenario, it is impossible to obtain recloser-fuse coordination using the conventional method with the standard characteristic.

As shown in Tables 3 and 4, using the proposed NSITC, the time margin between the fuse and recloser operation times is enhanced and can obtain an appropriate value which is at least 0.1 seconds, without or with DG added to the DN. Compared with the method of [3], the use of the proposed scheme reduces costs because there is no need for various measurement points in DNs and communication links between them and the recloser. Moreover, when DG units are added to the DN, using the method of [3] cannot obtain a proper time margin between operating times of the recloser and the fuses under almost all fault conditions, except L.L faults. As shown in bold in Tables 3 and 4, the required margin of 100 ms for the CTI cannot be achieved by using the method of [3].

Table 3

Results of recloser-fuse coordination on DN
at second scenario (under L.L.L and L.L fault)

Faulted line	L.L.L fault			L.L fault		
	t_f (s)	t_p (s)	t[3] (s)	t_f (s)	t_p (s)	t[3] (s)
L07	0.204	0.048	**0.122**	0.265	0.059	0.147
L21	0.201	0.075	**0.134**	0.262	0.083	**0.166**
L29	0.238	0.117	**0.165**	0.310	0.118	0.208
L33	0.272	0.153	**0.194**	0.355	0.149	0.247
L43	0.380	0.281	**0.292**	0.494	0.261	0.382
L47	0.397	0.297	**0.306**	0.514	0.275	0.400
L60	0.262	0.143	**0.185**	0.341	0.141	0.235
L66	0.271	0.155	**0.193**	0.353	0.151	0.247
L73	0.317	0.195	**0.228**	0.413	0.185	0.293
L78	0.356	0.229	**0.257**	0.463	0.214	0.334
L81	0.357	0.230	**0.258**	0.464	0.215	0.335
L84	0.399	0.267	0.291	0.518	0.247	0.379
L86	0.444	0.308	0.327	0.576	0.282	0.429
L90	0.433	0.298	0.318	0.562	0.273	0.416

Table 4

Results of recloser-fuse coordination on DN at second scenario
(under L.L.G and L.G fault)

Faulted line	L.L.G fault			L.G fault		
	t_f (s)	t_p (s)	t[3] (s)	t_f (s)	t_p (s)	t[3] (s)
L07	0.275	0.052	0.151	0.554	0.110	**0.324**
L21	0.246	0.076	**0.161**	0.256	0.086	**0.196**
L29	0.277	0.115	**0.197**	0.254	0.110	**0.219**
L33	0.319	0.150	**0.235**	0.300	0.145	**0.275**
L43	0.388	0.267	**0.337**	0.298	0.176	**0.314**
L47	0.417	0.282	**0.359**	0.325	0.194	**0.346**
L60	0.289	0.140	**0.216**	0.241	0.115	**0.219**
L66	0.278	0.151	**0.218**	0.213	0.105	**0.199**
L73	0.360	0.189	**0.275**	0.301	0.155	**0.288**
L78	0.422	0.220	0.320	0.376	0.199	**0.370**
L81	0.425	0.221	0.322	0.381	0.202	**0.376**
L84	0.487	0.255	0.370	0.460	0.250	**0.467**
L86	0.555	0.292	0.425	0.557	0.311	**0.586**
L90	0.541	0.282	0.412	0.542	0.300	**0.565**

6. CONCLUSION

Incorporating DG into distribution network may lead the recloser-fuse miscoordination. A new relaying scheme based on a developed time-current-voltage characteristic is presented for recloser-fuse coordination in distribution networks with DG, which is applicable in modern reclosers with embedded microprocessor-based relays. The proposed non-standard inverse time characteristic uses the faulted voltage and current magnitudes for fast operating time of the recloser to achieve fuse saving under transient fault conditions. The proposed method does not require any communication link between the recloser and DG units or the DN measurement points. The proposed scheme has been validated by simulation study on an Iranian practical DN under different fault types. It is shown that the operating time of the proposed characteristic in DN without DG is close to the standard characteristic of the recloser, whereas for the DG penetrated DN it is able to uphold self-adaptively discrimination time margin between the recloser and its downstream fuses. Also, it is shown in a comparative study that the proposed relaying scheme can maintain the coordination for higher DG penetrations than a recent adaptive method reported in the literature. Overall, it is shown that the proposed scheme can overcome shortcomings of conventional methods for the fuse-saving strategy in the presence of DG. The scheme is simple and cost effective when compared with recent methods which require costly communication links or fault current limiters.

APPENDIX

Detailed information about the DN is given in the Table A.1. In Tables A.1, each load is connected at the receiving end of the line and the average power factor for all loads is 0.9 lag.

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Table A.1

Lines and loads data of DN1

Line Name	From	To	R (Ω)	X (Ω)	Load (kVA)	Line Name	From	To	R (Ω)	X(Ω)	Load (kVA)
L01	B00	B01	0.113	0.144	84	L48	B47	B48	0.045	0.037	38
L02	B01	B02	0.126	0.161	0	L49	B48	B49	0.118	0.096	75
L03	B02	B03	0.030	0.024	154	L50	B48	B50	0.114	0.092	75
L04	B02	B04	0.089	0.114	213	L51	B50	B51	0.091	0.074	75
L05	B04	B05	0.049	0.062	151	L52	B50	B52	0.159	0.129	75
L06	B05	B06	0.098	0.125	0	L53	B52	B53	0.191	0.155	75
L07	B06	B07	0.745	0.605	0	L54	B53	B54	0.200	0.162	75
L08	B07	B08	0.101	0.082	19	L55	B26	B55	0.182	0.232	19
L09	B07	B09	0.067	0.054	150	L56	B55	B56	0.179	0.228	0
L10	B09	B10	0.109	0.089	19	L57	B56	B57	0.111	0.090	38
L11	B09	B11	0.186	0.151	19	L58	B56	B59	0.094	0.119	150
L12	B06	B12	0.049	0.062	0	L59	B59	B60	0.014	0.017	0
L13	B12	B13	0.025	0.021	236	L60	B60	B61	0.143	0.116	0
L14	B12	B14	0.066	0.084	19	L61	B61	B62	0.032	0.026	75
L15	B14	B15	0.162	0.207	19	L62	B62	B63	0.023	0.018	0
L16	B15	B16	0.134	0.171	188	L63	B63	B64	0.036	0.030	75
L17	B16	B17	0.260	0.332	75	L64	B63	B65	0.098	0.080	19
L18	B17	B18	0.109	0.139	19	L65	B60	B66	0.220	0.280	0
L19	B18	B19	0.166	0.212	0	L66	B66	B67	0.005	0.004	188
L20	B19	B20	0.069	0.056	75	L67	B67	B68	0.131	0.106	19
L21	B19	B21	0.175	0.142	19	L68	B66	B69	0.068	0.055	150
L22	B19	B22	0.027	0.035	38	L69	B66	B70	0.077	0.099	75
L23	B22	B23	0.080	0.102	38	L70	B70	B71	0.029	0.037	0
L24	B23	B24	0.107	0.137	0	L71	B71	B72	0.054	0.069	19
L25	B24	B25	0.052	0.042	19	L72	B72	B73	0.082	0.104	0
L26	B24	B26	0.067	0.086	0	L73	B73	B74	0.040	0.033	0
L27	B26	B27	0.049	0.062	150	L74	B74	B75	0.110	0.089	38
L28	B27	B28	0.034	0.043	0	L75	B74	B76	0.066	0.054	38
L29	B28	B29	0.309	0.251	120	L76	B73	B77	0.068	0.087	38
L30	B28	B30	0.194	0.247	150	L77	B77	B78	0.054	0.069	0
L31	B30	B31	0.117	0.149	75	L78	B78	B79	0.157	0.127	75
L32	B31	B32	0.050	0.064	0	L79	B78	B80	0.060	0.077	120
L33	B32	B33	0.263	0.214	75	L80	B80	B81	0.034	0.044	0
L34	B32	B34	0.176	0.225	150	L81	B81	B82	0.026	0.033	38
L35	B34	B35	0.193	0.246	75	L82	B82	B83	0.140	0.178	38
L36	B35	B36	0.165	0.211	150	L83	B81	B84	0.027	0.035	0
L37	B36	B37	0.176	0.225	0	L84	B84	B85	0.283	0.230	150
L38	B37	B38	0.033	0.042	75	L85	B84	B86	0.244	0.311	75
L39	B37	B39	0.190	0.242	75	L86	B86	B87	0.247	0.201	75
L40	B39	B40	0.054	0.069	0	L87	B87	B88	0.091	0.074	0
L41	B40	B41	0.045	0.037	75	L88	B88	B89	0.069	0.056	75
L42	B40	B42	0.136	0.173	0	L89	B88	B90	0.081	0.066	75
L43	B42	B43	0.091	0.074	75	L90	B86	B91	0.131	0.167	75
L44	B43	B44	0.068	0.055	0	L91	B91	B92	0.122	0.156	75
L45	B44	B45	0.272	0.221	75	L92	B92	B93	0.108	0.138	38
L46	B44	B46	0.227	0.185	75	L93	B93	B94	0.013	0.016	75
L47	B42	B47	0.204	0.166	75	L94	B94	B95	0.542	0.692	38

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