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A New Approach to Adaptive Setting of Distance Relays Using Setting-Group Function

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ABSTRACT

–Adaptive setting of distance relays usually suffers from several problems. This paper proposes a new method for overcoming some adaptive setting problems in interconnected power systems. Improvement of identifying fault location and subsequently faster operation of the protection system in disconnecting the faulted part from the main network are results of the proposed method. The method requires digital relays with telecommunication features and Setting-Group function at both ends of transmission. The proposed algorithm was applied to an actual network. The results show that the new method is flexible and efficient.

KEYWORDS: Distance Relay, Adaptive Setting, Backup Relay, Settings-Group

1. INTRODUCTION

Distance relays are widely used in protection systems of electrical networks. They act as main and backup protection in inter-connected power systems. Main relays are the closest ones to the faulted point and should operate as soon as possible. Backup relays help main relays if the latter cannot clear the fault.

Therefore, coordination among several main and backup relays is necessary in order to have minimum electricity outage. It is complicated especially when the power system is interconnected. The complexity of coordination problem increases where impedances of connected lines to every bus were far from each other [1]. Moreover, when a relay acts as a backup of several main relays (a large number of lines connected to a bus), the constraints of the coordination process will increase and the coordination problem will be more difficult. Then, all the main and backup relays in a protection system must be coordinated for minimum electricity outage.

Previous papers presented different methods for coordination. A new strategy (denoted P-SS) proposed in [1] estimates the correct fault zone. It does not depend on fixed boundaries for backup zones. This method zone-1 increases up to 100% of the protected line. Also, zone-2 and zone-3 cover the entire length of any next line and any next line to zone-2, respectively. Communication links between main and backup relays are needed in this method. In [2], a method is presented that increases coverage of zone-2 without overlapping problems. This method is based on calculated impedances by relays in max and min generation situations. In addition, adaptive protection was explained in [2]. The method explained in [3] describes an adaptive method which is based on real-time measurements. Phase measurement units (PMU) are necessary for implementation of the method. Relay setting will change based on the parameters measured. Parallel lines make problems for a protection system because of the mutual coupling effect. Several researchers have studied this case. For instance, [4] presented a method to overcome this problem. This method works with comparing measured impedances of each parallel line together and six current signals are gathered instead of three signals. Three added signals are from adjacent line. Zone-3 can contribute in cascading failure because reach of this zone usually covers a big area of the network. Ref. [5] presented a method to reduce this flaw and suggested reverse zone-3 setting that can be effective in interconnected networks and reduce the probability of cascading failure of system.

This paper proposes a method for increasing reach of backup zone without any overlapping problem between main and backup relays. In the proposed method, local communication links (between all relays of each substation) and remote communication links (between beginning and end of each line) is needed. In addition, relay capability of saving several Setting-Groups is necessary. Setting-Groups should be changeable by sending appropriate signals immediately after fault occurrence. This paper is based on applying these Setting-Groups to each relay during a fault. Selection of appropriate Setting-Group is done by means of communication links. The main advantage of the proposed method is that each relay acts as backup of only one relay at the time of fault occurrence; therefore, the constraint of coordination problem will decrease. Applying the proposed method into a protection system requires

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some conditions which are discussed in section 3. The proposed scheme was examined via computer simulation of a real practical network with 45 buses and 90 distance relays. Simulation results confirm the ability of the proposed method in improving performance of the protection system.

2. Problem statement

Application of distance relays to the protection of transmission lines usually involves three zones. Every zone at least has two adjustable parameters (time and impedance). The first zone time adjusts for instantaneous action and acts as the main protection all the time. The second and third zones act as backup protection which protects remote bus and remote lines, respectively. The coordination between main and back up zones achieved by adjusting the time by 0.3–0.5 s (15-30 cycle) for zone-2 of relays and about 1.0 s (90 cycle) for zone-3 [5]. Impedance adjustment of backup zones depends on the network situation. Several traditional methods have been proposed [6]-[7], which are used in protection systems and are summarized in Table.1.

Table 1: Traditional methods of distance relay setting.[6]

Setting method	Zone1	Zone2	Zone3
Method 1	$(0.8\,to\,0.85)Z_1$	$Z_1+0.5Z_{2S}$	$Z_1+Z_{2L}+0.25Z_{3S}$
Method 2	$(0.8\,to\,0.9)Z_1$	$(1.2\,to\,1.5)Z_1$	$Z_1+(1.20\,\mathrm{to}\,1.80)Z_2$
Method 3	$(0.85)Z_1$	$0.85(Z_1+0.85Z_2)$	$0.85(Z_1+0.85(Z_2+0.85Z_3)$
Method 4	$(0.80)Z_1$	$Z_1+0.5Z_{2S})$	$1.20(Z_1+Z_{2L})$
Method 5	$(0.80)Z_1$	$Z_1+0.25Z_{2S})$	$Z_1+Z_{2L}+0.25Z_{3L}$

In Table 1 Z_1, Z_2, Z_3 are impedances of the protected line, remote line and adjacent of remote line, respectively. Letter "S" and "L" refer to the shortest and the longest connected lines.

In an interconnected network, each relay may act as a backup of several relays. This situation makes constraint of considering shortest or longest line in protection schemes. In traditional coordination methods, usually the worst constraint is considered between all constraints because the location of the fault is unknown. The performance of protection system will improve if the constraint can be selected according to fault location. With recent advances in communication technology and digital relays, the above goal is achievable, and this paper is going to propose a new method in this regard.

3. Proposed method and requirements

Requirements

Before introducing the new method, it is necessary to explain requirements that are unavoidable for implementation of the proposed scheme.

- Adaptive relays which can change their Setting-Group during fault occurrence are needed. Relays that are used in adaptive protection system usually have this capability.
- Local communicational network between all relays of substation is needed for interchanging signals and commands.
- Remote communication network for transferring data between beginning and end of lines is necessary. The needed network is not so complex and is used in pilot protection schemes.
- Finally, an intermediate unit (denoted I-U) is needed to create the link between remote and local communication systems.

3.1. Proposed method

The proposed method is based on P-SS method [1], where backup zones do not have fixed boundaries. In the proposed method, backup zones have several fixed boundaries which have been saved in Setting-Groups of each relay. In fact, the number of Setting-Group which is saved in each relay is equal to the number of relays supported by this relay.

During fault occurrence, backup relays change their Setting-Group based on fault location. It deals with communicational networks and I-U. In other words, the main relay can share data with backup relays using communication networks and I-U. The main relay sends a signal to I-U with local communication network and I-U will send appropriate signal to other relays which are in the substation. Then, each relay that receives signal from I-U sends a signal to backup relays via remote communicational network, and backup relays will change their Setting-Group based on the received signal.

To describe the proposed method, let us consider a simplified single-line diagram which can be a portion of an interconnected power system as Figure 1. Suppose that all lines have the same construction that the length can be used instead of impedance. If a symmetrical 3-Phase fault happens in a marked location, R3 and R5 act as main relays while R6 and R1 are backup relays for R3.

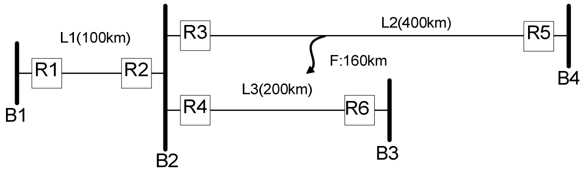

Figure 1: Simplified power system

After fault occurrence, zone-1 of R3 is active and tries to remove the fault. At the same time, it sends a signal to I-U which informs that its requirement to support. This signal is sent via a digital code which is explained in Section 3.2.3. Then, R4 and R2 receive the signal from I-U that contains digital code. After that, R2 and R4 will communicate via remote network and inform R1 and R6, respectively. So, R1 and R6 changed their settings based on received signals in order to be the proper one for supporting R3. In the following subsections, the proposed method will be explained in greater detail.

3.1.1. Relay coding

The first stage in the proposed method is coding all relays. Since new relays are usually digital, binary coding is a good option and can be supported by relays and I-U. For instance, the number of each relay in binary format can simply be taken as the code of relay. Table.2 shows coding for above example.

Table 2: Relay coding

Relay number	Relay code
R1	0001
R2	0010
R3	0011
R4	0100
R5	0101
R6	0110

3.1.2. Determination of Setting-Groups

After defining code for all relays, the next step for implementing the new method is Setting-Group determination. For this reason, we have to set up Main-Backup table that shows which relays act as backup of which relay. Column 1 and 2 of Table 3 show the portion of Main-Backup table for the system under discussion. This table must be completed via main relay code and Saved Setting-Group columns. Setting-Group-1 and Setting-Group-2 will be saved in R1 for supporting R3 and R4, respectively. Also, Setting-Group-3 and Setting-Group-4 will be saved in R6 for R2 and R3, respectively.

In order to determine Setting-Group-1, the probability of fault occurrence in L3 is considered to be zero. So, just L2 is considered for adjusting Setting-Group-1 which is related to R3. This means that the constraints of the shortest and longest line are not applicable in Setting-Group determination because at any stage of the process only one of remote lines is considered. The procedure will repeat for R4 and also the other relays.

Table 3: Setting group with main relay and backup relay

Back up relay	Main relay	Main relay code	Saved Setting-Group
R1	R3	0011	Setting-Group-1
R1	R4	0100	Setting-Group-2
R6	R2	0010	Setting-Group-3
R6	R3	0011	Setting-Group-4

3.1.3. Proposed algorithm

This section gives an overview of the proposed method by using a flowchart diagram which is shown in Figure 2. The process starts with gathering local relays data by I-U every cycle (20ms for 50 Hz systems). Then, it checks fault occurrence and main relay code in two ways:

1. One of relays detects the fault in its zone-1 and informs I-U via sending self code in addition to sending signal to the breaker for fault clearing. In this situation, the breaker failure can be unfavorable and backup relay operation can be very important.
2. If the main relay does not detect fault occurrence, other relays can detect reverse fault via reversed zone-3 [5]. In this situation, U-I will receive data from all relays except the main relay, and it can detect main relay code.

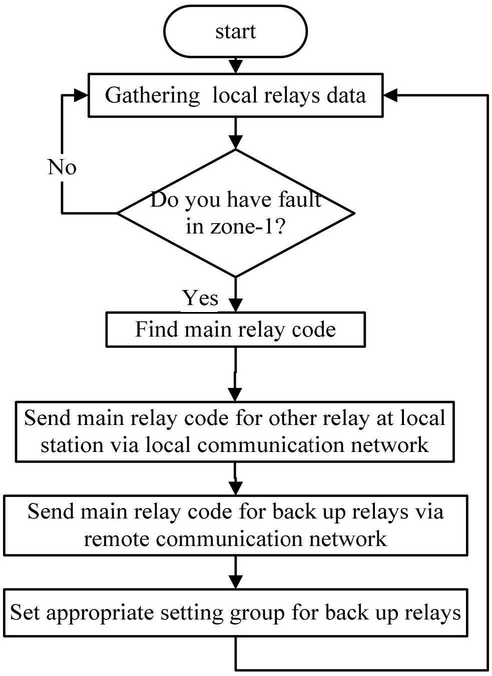

Figure 2: Proposed algorithm

In the next stage, I-U sends the main relay code to other relays in the local station via local communication network. Then, each relay will send main relay code to remote relays which act as backup for the main relay. Finally, each of the backup relays will select appropriate Setting-Group based on the received code.

3.1.4. Advantage and disadvantage of the method

As explained in Section 2, reach of zone-2 of backup relays is affected by network configuration especially where lines impedances are very difference from each other. In this situation, the shortest line constraint will affect zone-2 of backup relays and will decrease its reach.

Using the proposed method, reach of zone-2 of backup relays covers at least 50% of every connected line without considering the effect of the other connected lines where the conventional method is used for Setting-Group determination. This percentage can increase more that 50% if the method in [2] is used for Setting-Group determination biased on max and min generation. In fact, coverage of zone-2 of backup relays will increase. Therefore, some of the places that were out of coverage of zone-2 before implementing this method are now covered by zone-2. Then protection system can remove the fault faster if the main relay cannot clear the fault and fault occurs in places added to reach of zone2.

The other advantage of the proposed method appeared where two voltage levels are connected together with transformer. Since transformer impedance is higher than connected lines, zone-2 setting of backup relay will not efficient because it could not protect the other side of voltage. It is obvious that using this method can remove this defect from the protection system.

Clearly, if impedances of connected line are equal, or the number of connected lines is less than 3, the proposed method cannot improve efficiency of the protection system.

4. Simulation

4.1. Case study

Bakhtar Regional Electrical Company (BREC) 230KV network was selected to implement the proposed method. This network is a part of Iran's interconnected power system consisting of Markazi, Hamadan, and Lorestan provinces). Figure.3 is its single-line diagram. It has 45 transmission lines and 90 distance relays. Mutual effect between parallel lines was ignored. All relays are the same type and have the same features. Mho character was selected for all relays without any offset setting. Zone-2 and zone-3 time setting were 300ms and 600ms, respectively. The operation time of circuit breakers was considered 20ms. For the Setting-Group changing that contains local and remote communication network time, the operation time was considered 50ms [8]-[9]. Noise interference in communication networks was disregarded. CT saturation was neglected in the simulation process. In addition, generators and transformers did not have any protection scheme.

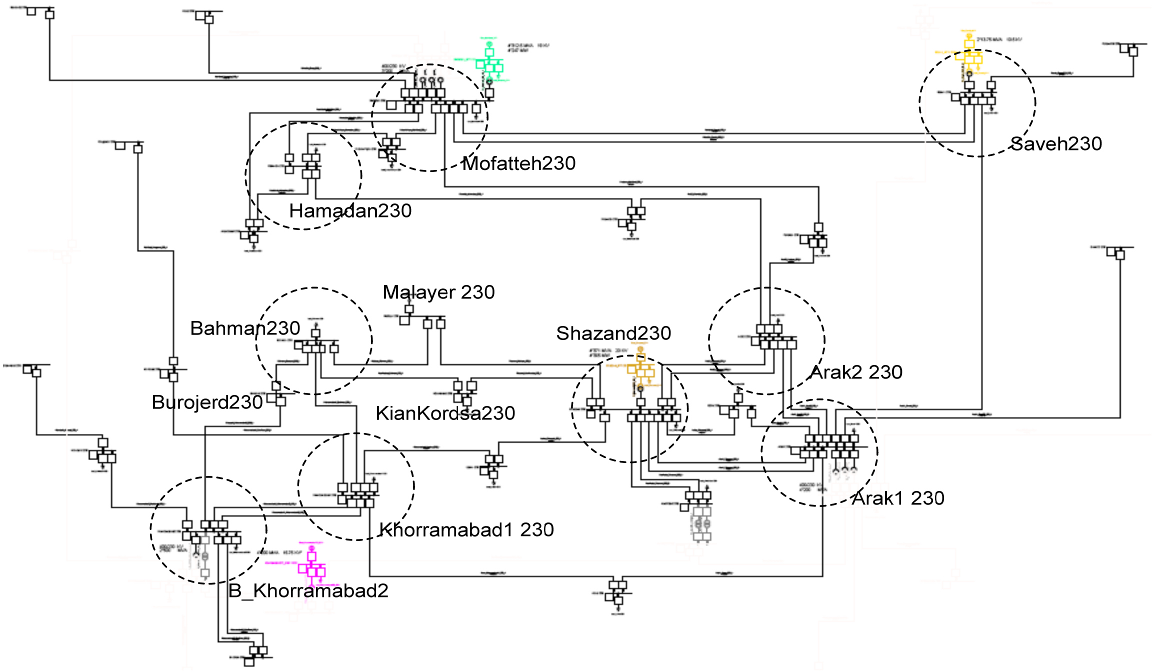

Figure 3: Case study (BREC 230-KV power system)

4.2. Simulation Results

As mentioned in section 3.2.4, if impedances of connected lines are equal or if there are fewer than 3 connected lines, the proposed method cannot improve protection system efficiency. All buses that have more than 2 connected lines are marked by dashed circles. All illustrated buses can be selected to implement the proposed method. The 230-KV substation Bahman is one of those buses that have 4 connected lines as Figure. 4 shows, and was selected for the purpose of presenting simulation results. Table.4 gives length of connected lines which is different from each other. Table 5 is part of the main-backup table of the network related to the Bahman Substation. Setting-Group-1-1025 is saved in R1025 to act as backup of R1022 when it receives 0010 code from R1023 (remote relay), etc. The network was simulated using two protection schemes in DigSilent software.

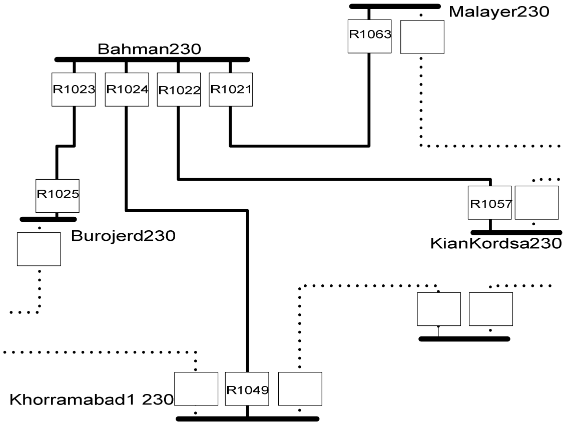

Figure 4: Bahman Substation and remote buses redrawing

Table 4: Data of Bahman Substation connected lines

Line Name	Sending bus	Receiving bus	Length (km)
Bahman_Burojerd_1	Bahman230	Burojerd230	33
Khorramabad1_Bahman	Khorramabad1230	Bahman230	110
KianKordsa_Bahman	KianKordsa230	Bahman230	40
Malayer_Bahman	Malayer230	Bahman230	45

Table 5: Part of main-backup table of the network related to Bahman Substation

Back up relay	Main relay	Main relay code	Saved Setting group
R1025	R1022	0010	Setting-Group-1-1025
R1025	R1021	0011	Setting-Group-2-1025
R1025	R1024	0100	Setting-Group-3-1025
R1049	R1023	0001	Setting-Group-1-1049
R1049	R1022	0010	Setting-Group-2-1049
R1049	R1021	0100	Setting-Group-3-1049
R1057	R1025	0001	Setting-Group-1-1057
R1057	R1021	0010	Setting-Group-2-1057
R1057	R1024	0011	Setting-Group-3-1057
R1063	R1025	0001	Setting-Group-1-1063
R1063	R1022	0011	Setting-Group-2-1063
R1063	R1024	0100	Setting-Group-3-1063

4.2.1. Case 1: Conventional protection schemes

In this case, a conventional protection scheme (for example First method in Table 1) is used for relay setting. Relay coordination is done by DigSilent Programming Language (DPL) according to the algorithm above and Table 6 shows the results.

Table 6: Settings obtained in Case 1

Relay	Zone-1	Zone-1 angle	Zone-2	Zone-2 angle	Zone-3	Zone-3 angle
R1025	0.94	80.06	3.30	79.92	5.19	79.86
R1049	3.14	80.06	3.30	79.92	5.19	79.86
R1057	1.14	80.06	3.04	80.06	4.44	80.06
R1063	1.28	80.06	3.71	81.44	5.44	81.29

To verify the performance of coordination process, a symmetrical three-phase fault at 47% of Khorramabad1_Bahman line is simulated. Main relay for this fault are R1024 and R1049. R1024 is located in B-Bahman substation and have R1025, R1063, and R1057 as backup. Figure 5 illustrates time of operation for main and backup relays. It can be seen that fault was detected in zone-1 of R1024 and zone-3 of R1025, R1063, and R1057.

4.2.2. Case 2: The proposed method

Another simulation is carried out to test the ability of the proposed method. As mentioned in section 3-2-3, the first step is determining Setting-Group of relays. This is done using the conventional method in case 1 with the aim of developing DPL in this project. Table 7 shows the calculated Setting-Groups of backup relays (R1025, R1063, and R1057). With a small glimpse of Table 7, it can be concluded that each Setting-Group related to R1024 has promoted zone-2 than the other Setting-Group which is saved in the same relay, because R1024 protects the longest connected line.

To compare performance of the proposed method with that of the conventional method, a fault identical to Case 1 is simulated in the network with the new scheme. Figure 6 shows operation time for each relay. As in the previous method, the main relay detected the fault in its zone-1. But backup relays detect this fault in their Zone-2. So clearing time decreased to 370 ms instead of 620 ms. Zone-2 time adjustment is 300 ms, and 20 ms and 50 ms are considered for circuit breaker operation and communication delay, respectively. A decrement of 250 ms in fault clearance in case of main relay failure which is about 40% can prevent many potential damages such as generator trip, fault spread, instability, or blackout from the network. Therefore, the proposed method is a great improvement in backup protection.

5. CONCLUSION

This paper proposed a new adaptive method for improving protection system of interconnected power plants. The method is based on local and remote communication facilities in substations. The other parameter used in the method is Setting-Group saving. Each Setting-Group is determined to protect a remote line without considering the effect of the other connected lines. During a fault, a proper Setting-Group that has been saved in backup relays will load, and their backup zones will change in order to protect the faulted remote line. This process causes a significant decrement in fault clearing time in the case of main relay failure if there are more than 2 connected lines and if they have different impedances. Simulation results on an actual network in Iran prove the ability of the proposed method to improve system protection

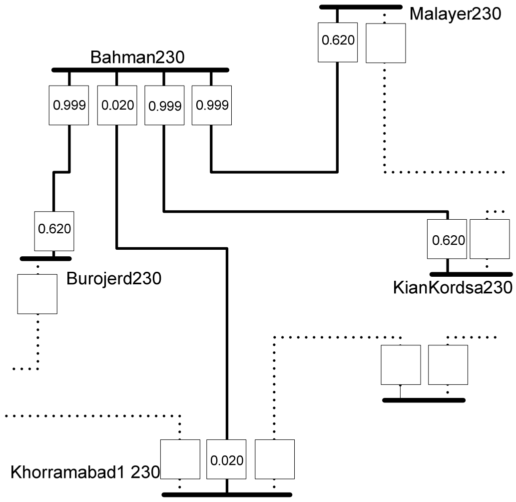

Figure.5: Tripping time of relays before applying the proposed method

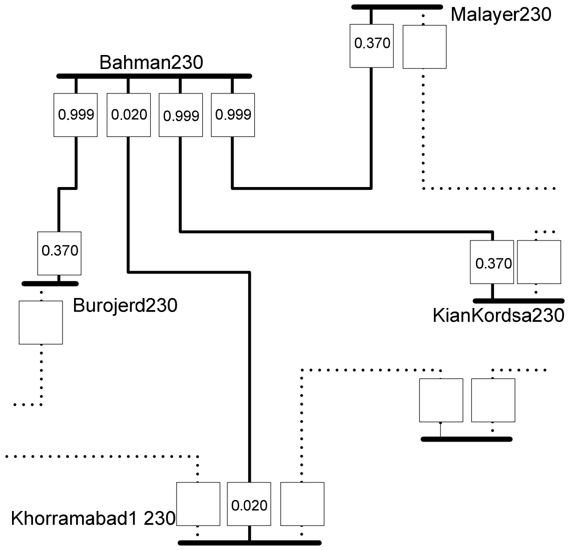

Figure.6: Tripping time of relays after applying the proposed method

Table.7: Part of Setting-Group saved in relays

Setting-Group	Main relay	Zone-1	Zone-1 angle	Zone-2	Zone-2 angle	Zone-3	Zone-3 angle
Setting-Group-1-1025	R 1022	0.94	80.06	3.30	79.92	5.19	79.86
Setting-Group-2-1025	R 1021	0.94	80.06	3.98	79.89	6.35	79.84
Setting-Group-3-1025	R 1024	0.94	80.06	5.63	82.37	9.63	77.02
Setting-Group-1-1049	R 1023	3.14	80.06	3.30	79.92	5.19	79.86
Setting-Group-2-1049	R 1022	3.14	80.06	3.98	79.89	6.35	79.84

Setting-Group-3-1049	R 1021	3.14	80.06	3.63	82.37	7.63	80.02
Setting-Group-1-1057	R 1025	1.14	80.06	3.63	82.37	5.63	79.02
Setting-Group-2-1057	R 1021	1.14	80.06	3.04	80.06	4.44	80.06
Setting-Group-3-1057	R 1024	1.14	80.06	5.81	81.44	9.71	81.44
Setting-Group-1-1063	R 1025	1.28	80.06	4.44	80.06	7.63	78.87
Setting-Group-2-1063	R 1022	1.28	80.06	3.71	81.44	4.44	81.29
Setting-Group-3-1063	R 1024	1.28	80.06	7.71	80.06	9.71	79.21

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