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ANALYSIS OF OVER CURRENT RELAY AND GROUND FAULT RELAY PROTECTION SYSTEM IN SUB-STATION SP-2 TANAH MIRING USING RELAY COORDINATION WITH ETAP BASED

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Abstract
Short-circuit often occur in electricity sub-station SP-2 Tanah Miring, Merauke -Papua which caused by malfuction of Over Current Relay (OCR) and Ground Fault Relay (GFR). In enhancing the performance, it takes analysis of relay coordination using ETAP. At maximum load of feeder SP-9 (917 A) an OCR setting is 4.5 A with TMS 0.46 seconds, GFR setting is 4.58 A with TMS 0.17 seconds. At minimum load (324 A) OCR setting is 1.62 A with TMS 0.29 seconds as for the GFR setting is 1.62 A with TMS 0.22 seconds. At the maximum load of feeder Kebun Cokelat (995 A) an OCR setting is 4.97 A with TMS 0.46 seconds as for GFR set is 4.97 A with TMS 0.17 seconds. At minimum load 100 A, OCR setting is 0.5 A with TMS 0.43 seconds while GFR setting is 0.5 A with TMS 0.35 seconds. Furthermore, if the minimum load reach 98 A then the coordination time of GFR and OCR is 0,5 seconds. This analysis found that relay prohibited to operate above 1100 A (maximum) and below 98 (minimum) due to if it working out of the load range then the coordination time would not meet the manual standard.

Keywords:
FAULT;
OCR;
GFR;
Load;
TMS;

1.0 INTRODUCTION

Distribution systems are particularly susceptible for disorder-distractions that can lead to interconnection of electrical power from generation to consumer. To address the problem, it would require adequate protection measures to maintain the continuity of electricity distribution to consumers. The protection system can reduce risk of damage to the equipment and natural disturbances [1].

Relay coordination is an important aspect in the protection system design as coordination schemes must guarantee fast, selective, and reliable relay operation to isolate the power system faulted sections with a minimum of time by separating the parts of the compromised system from the others in order to continue operating normally [2]. There are several components of the protection system at the sub-stations, some of which are relay. Maintenance procedure is really need to be taken by routine to prevent coordination failures. If some of deviation is found during maintenance, then the relay must be reset therefore the performance of relay is always in optimal condition. An aspect of relay coordination need a great concern in reviewing the performance of the relay [3].

The essential purpose of relay coordination is to determine the character and the devices setting, therefore if a short circuit happened than the device will remain intact [4]. Relay coordination determines the reliability of a protective system. OCR (Over Current Relay) and GFR (Ground Fault Relay) coordination need to be maintained. OCR and GFR area kind of relay that can protect distribution systems from short circuit and over currents[5]. Talitha. sari, etc., stated that in optimization implementation of power plant production, the continuity of a system distribution is one of essential things that need great attention. One of the main part of this continuity is the installation of relay as a protection system of short circuit and over current[6].

According to the primary data from PT PLN AUIW Merauke stated that the most common fault happened in sub-station SP 2 Tanah Miring was a short circuit. In 2017, a short circuit was occurred at sub-station SP-2 which damage the protection system devices and caused financial losses. By seeing this issues furthermore a relay resetting is needed to be analyze. Sub – Station SP-2 Tanah Miring has two feeders which are SP -9 and Kebun Cokelat (the name of the feeder is according to its area). Over current relay and ground fault relay was installed at Sub-station SP -2 Tanah Miring as its protection system. The OCR and GFR were last in review and set up in 2010. A new relay coordination has to be done again, to evaluate the new optimal relay settings [3]

The trend data showing that the number of customers and connected power are increase significantly each year other side the time delay of OCR and GFR is too long if there is a short circuit attack the distribution network. Hence then the relay need to be resetting. Given the problem's consciousness, then the researchers conduct a simulation using coordination relay with ETAP 12.6.1 based. The purpose of this research is to knowing the over current that caused by short circuit using simulation feeder coordination of distance, determine time multiple setting for over current relay and ground fault relay at maximum and minimum load based on standard range that stated in Manual Book Schneider.

2.0 METHODOLOGY

2.1 Short Circuit

Short circuit is an electrical circuit that caused by fault between voltage components which produce an over current that could damage the electricity devices.

A short circuit constratraints must be represent as follow [7] :

2.1.1 Three phase short circuit

$$I_{sc}\ 3ph = \frac{VL-N}{Z1} \quad (1)$$

2.1.2 Two phase short circuit

$$I_{sc}\ 2\ ph = \frac{VL-N}{Z1+Z2} \quad (2)$$

2.1.3 One phase short circuit

$$I_{sc} 1\ ph = \frac{3VL-N}{Z1+Z2+Z0} \quad (3)$$

2.2 Source Impedance

On bus 20 kV an impedance can be expressed as below [8] :

$$X_s = \frac{KV^2}{MVA} \quad (4)$$

2.3 Transformer Impedance

The equation of transformer impedance can be presented as below [9] :

$$Xt\ (pada\ 100\%) = \frac{KV^2}{MVA} \quad (5)$$

2.4 Feeder Impedance

The magnitude of feeder impedance depend on feeder area which determined by the configuration of the feeder column that using in power distrbution system 20 kV. Generally, the equation of feeder impedance can be express as following [10] :

$$Z = (R + _jX) \quad (6)$$

2.5 Equivalent Impedance

The calculation of equivalent impedance based on the magnitude of positive sequence impedance (Z_{1eq}), negatif sequence impedance (Z_{2eq}) and zero sequence impedance(Z_{0eq}) from the fault point to source section. The following equation is used to determine the equivalent impedance [11]:

$$Z_{1eq} = Z_{2eq} = Z_{s1} + Z_{t1} + Z_{1\ feeder} \quad (7)$$

2.6 *Over Current Relay*

OCR is a relay that works based on the over current that passes through it. The relay that installed at sub-station calculated according to the maximum load -currents. Otherwise, for a standard inverse is setting from 0.1-1.1 I_{max} [12] The setting of minimum time delay for over current relay is commonly no lowest than t = (0.3 +0.4) = 0.7 seconds. I_{fault} is picking up to define the number of TMS (Time multiple Setting). For OCR the fault - current was picking up from short circuit three-ph at 100% coordination of distance. The lowest operational time of relay *t* = (0.3 +0.4) = 0.7 seconds. In this work, the following formula is used to approximately represent the OCR characteristics [13] [14]:

$$I_{SET(PRIMER)} = 0{,}1 \times I_{load} \quad (8)$$

$$I_{SET(SEKUNDER)} = I_{SET(PRIMER)} X \frac{1}{RatioCT} A \quad (9)$$

$$t = \frac{0{,}14TMS}{\left(\frac{I_{FAULT}}{I_{SET}}\right)^{0{,}02} - 1} \quad (10)$$

2.7 *Ground Fault Relay*

The GFR is a relay which has a function to secure the system from over current which caused by soil interference and detect short circuit as well. Time coordination of ground fault relay is commonly setting based on grading time among protection devises according with IEC 60255 as much *t* = 0.3 seconds. The constrain of GFR operation time can be express as below [15] :

$$t = \frac{0.14TMS}{\left(\frac{I_{FAULT}}{I_{SET}}\right)^{0{,}02} - 1} \quad (11)$$

where *t* is the relay operation time; I*fault* is the maximum 3-ph short – circuit current , Is*et* is the pickup current.

Reseach flow diagram is determine as below :

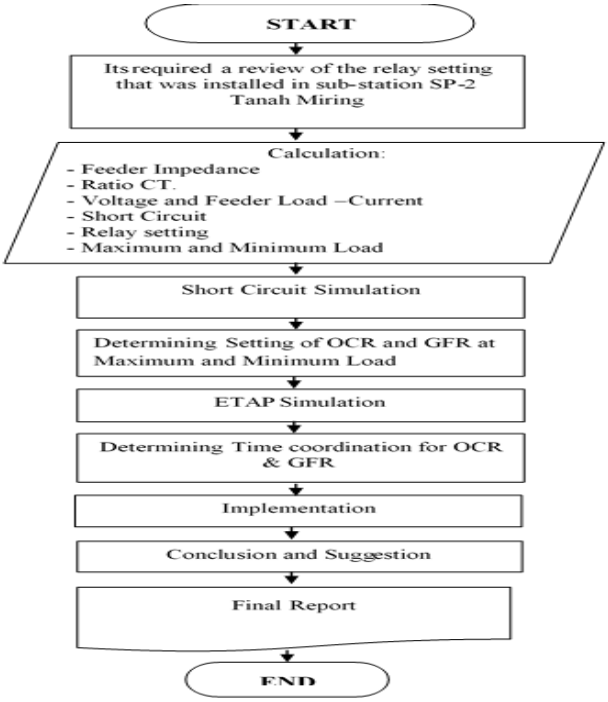

Figure 1. Research Flow

3.0 RESULANTS AND DISCUSSION

3.1. Feeder Impedance Analysis

Feeder impedance is calculated based on length of the feeder (km), section area, diameter of cable (mm) and column configuration at feeder SP 9 and feeder Kebun Cokelat as well. Furthermore positive sequence impedance (Z1), negative sequence impedance (Z2) and zero sequence impedance (Z0) could be determined as presented as below figure:

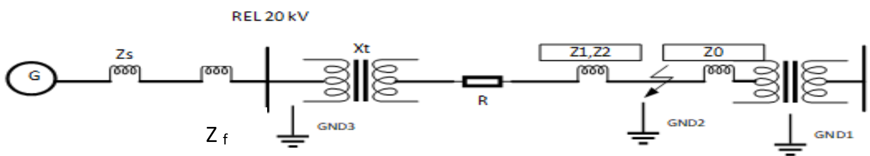

Fig. 2. Positive Sequence Impedance, Negative sequence Impedance, zero sequence Impedance

Based on above sequence (fig.2.) has lead to determine the feeder impedance as presented in below table:

Table 1. Calculation Result of Feeder Impedance at Given Per Lenght

Length (%)	Z1	Z2	Z0
25%	1,152 + j0,893	1,152 + j0,893	1,522 + j4,11175
50%	2,304 + j1,786	2,304 + j1,786	3,044 + j8,2235
75%	3,456 + j2,679	3,456 + j2,679	4,566 + j12,33525
100%	4,608 + j3,572	4,608 + j3,572	6,088 + j16,447

Impedance feeder calculations are simulated at a coordination distance of 25%, 50%, 75% and 100 % therefore Z1, Z2 and Z0 will be used as a variable to count the magnitude of equivalent impedance.

3.1 Equivalent Impedance Analysis

Calculation of ekquivalent feeder based on impedance sequence positive, negative and zero. In details, the analyzing results are listed in the following tables:

Tabel 2. Equivalent Impedance Result

Feeder Length (%)	Z1 Eq	Z2 Eq	Z0 Eq
25%	1,152 + j6,893	1,152 + j6,893	121,522 + j16,11175
50%	2,304 + j7,786	2,304 + j7,786	123,044 + j20,2235
75%	3,456 + j8,679	3,456 + j8,679	124,566 + j24,33525
100%	4,608 + j9,572	4,608 + j9,572	126,088 + j28,447

Analysis of equvalent impedance is taken based on source impedance magnitude, transformer reactant, and grounding resisntance in determining the magnitude positive sequence impedance, negative sequence impedance, zero sequence impedance from the faulted sections to source area. The simulation of equivalent impedances were calculated at coordination distance of 25%,50%,75% and 100 %. This was done due to from the fault section to the source is connected by series model. The sequence positive ($Z1_{eq}$) and negative ($Z2_{eq}$) can be formulated in addition formula. Other hand, the zero sequence ($Z0_{eq}$) is calculated from the transformer power of sub-station SP-2. The result of this calculation analysis then became a variable to count the magnitude of short circuits at feeder SP-9 and Kebun Cokelat.

3.2 Short Circuit Analysis

The result of short circuit analysis is as shown in table 3:

Table 3. Short Circuit Simulation Analysis Result

No	Coordination Distance	Three-ph (A)	Two-ph (A)	One-ph (A)
1	25%	1652.26	1430.9	271.94
2	50%	1422.08	1231.5	261.29
3	75%	1236.05	1070.4	251.14
4	100%	1086.93	941.3	241.51

Short circuit are calculated according to each type. Short circuit 3-ph are calculated based on impedance of positive sequence (z1eq) and neutral voltage phase system (20 Kv) at feeder SP -9 and Kebun Cokelat. Short circuit 2-ph are estimated based on the magnitude of positive impedance sequence (Z1eq), negative impedance sequence (Z2eq) and the phases system of 20 kV distribution power. Short circuit 1-ph is calculated by the number of positive impedance sequence (Z1eq), negative impedance sequence (Z2eq) and the zero impedance sequence (Z0eq) which are simulated at coordination of distance 25%, 50%, 75% and 100%. As expected from equation (1,2,3), the magnitude of short circuit 3-ph, 2-ph, 1- ph were listed at table 3.

In this work, resetting of relay considering to pick-up 100% coordination of distance. The magnitude of short circuit for OCR with 3-ph is 1086.93 A. Otherwise, the magnitude of short circuit for GFR with 1-ph is 241.51A. The selection of systems 3-ph and 1-ph aimed to knowing the relay coordination reliability for OCR & GFR at 1100% coordination distance with minimum and maximum current-load.

3.3 Setting OCR and GFR Result for Main Load

The analyzing results of OCR and GFR setting are listed in the following tables:

Tabel 4. Result Analysis Of Relay Time Coordination For Main - Load

Feeder	Relay Time Coordination Setting Result	
	OCR (seconds)	GFR (seconds)
SP 9	0.409	0.44
Kebun Coklat	0.41	0.403

In this section, the relay settings are calculated based on short circuit magnitude . The existing current –load of feeder SP-9 is 700 A and Kebun Cokelat feeder is 1000 A. When a short circut occurr at 100% coordination distance at 1 ph with its current magnitude is 241.5 A and for 3 – ph with current magnitude is 1086.93 A then the operational time of relay was slowing down. This analysis was formulated based on costumer demand exclude its operation load. In determining the accurate setting value, therefore OCR and GFR are calculated according maximum load and a minimum load in operation condition which described in the following section.

3.4 Setting OCR and GFR Result for Maximum and Minimum Load

The calculation result of OCR and GFR setting at maximum and minimum load is given in table 5 as below:

Tabel 5 . The Result Analysis of Time Coordination OCR and GFR at Maximum and Minimum Load

Feeder	Relay	Relay Time Coordination	
		$I_{max\text{-}load}$ (seconds)	$I_{min\text{-}load}$ (seconds)
SP- 9	OCR	0.46	0.29
	GFR	0.17	0.22
Kebun Cokelat	OCR	0.46	0.43
	GFR	0.17	0.35

Data of feeder - load curve (January 2020-March 2020) are using to determined the relay time coordination that showing in **table 5** . Load-current data for each feeder states that the maximum load seen from January until March 2020 at the feeder SP-9 is 917 A and the maximum load-current of feeder Kebun Cokelat is 995A. Instead, the minimum of the feeder SP-9 occurs as much as 324 A and feeder Kebun Cokelat occurs as much as 100 A.

From above result observed that the researchers' settings number for the feeder SP-9 and Kebun Cokelat of both OCR and GFR have a set of time setting that meets wih the requirement standard of relay that stated in manual book (standard ≤ 0.5 seconds). That means, if a short circuit happened at 100% dictance coordination of feeder SP-9 and Kebun Cokelat with 1- ph and 3 - ph at maximum and minimum load conditions then the OCR and GFR operational time is still in optimum range.

3.5 OCR and GFR Limit for Maximum and Minimum Load

In this section, to determining the work limit of OCR & GFR at optimum and minimum current-load then below calculation are formulated as listed in table 6:

Tabel 6. The Result Calculation of Relay Work Limit at Maximum and Minimum Load

Maximum Load (A)	Minimum Load (A)	OCR Time Coordination Setting (Seconds)	GFR Time Coordination Setting (Seconds)
1100	98	0.5	0.5

The result analysis in table 6 stated that in operation condition of feeder SP-9 and feeder Kebun Cokelat, in case the maximum load increase up to 1100 A then the time coordination for both OCR and GFR still remain 0.5 seconds. Onother side, when the minimum load decrease up to 98 A then the time coordination for both OCR and GFR still remain 0.5 seconds as well. This analysis show that relay is prohibited to operate above 1100 A (maximum load) and below 98 A (minimum load) due to if it working out of the load range then the coordination time will not meet the manual standard requirement. This aspect is the most important factor which PLN UIW need to have a great concern in enhancing the continuity of the relay coordination.

3.6 Simulation Coordination Analysis

By seeing the relay coordination time as listed above, therefore simulation of relay cordination using ETAP is needed to be taken as an important part to determining the work effectivity of relay time coordination of 0.5 seconds at 1100 A. ETAP simulation is the main component of below scheme, it communicate with all relays. This simulation are listed in below figures:

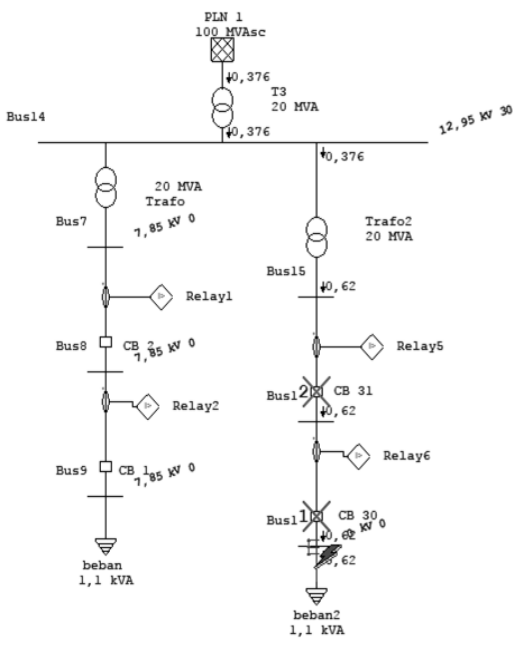

Fig. 3. Relay Coordination at Maximum Load using ETAP 12.6.1

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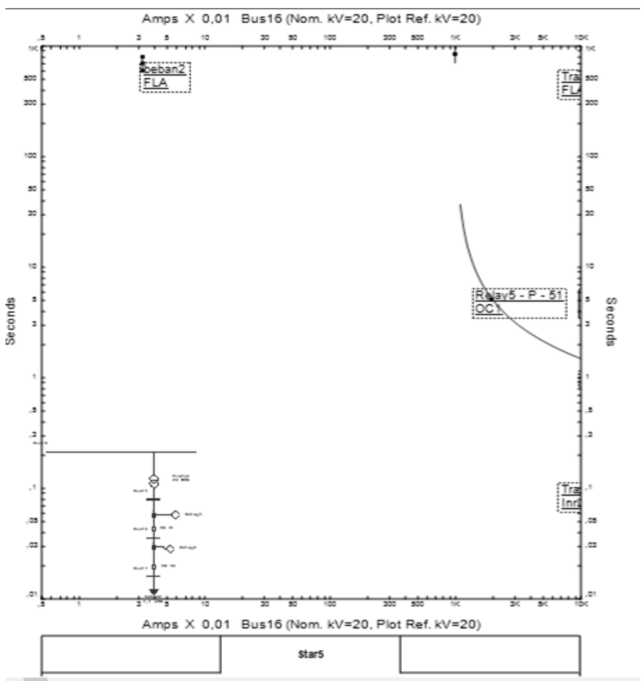

Fig. 4. Curve of Coordination Time-Current Correlation at Maximum Load

Observation of relay coordination at maximum load is doing by seeing the *time-current correlation* curve when it given a load as much 1100 A at 100% coordination disctance in 3-ph on bus 1. The simulation result found that if a short circuit accour on bus 1 then relay number 6 will work to coordinate the circuit breaker (CB 30) to isolate the fault area. Furthermore *relay* 5 will work to coordinate CB 31 to isolate the fault area. Based on a review of the current *curve - time correlation* found that when a short circuit accour on bus 1 with 20kV then a relay coordination time is 0.5 seconds (still meet the standard requirement).

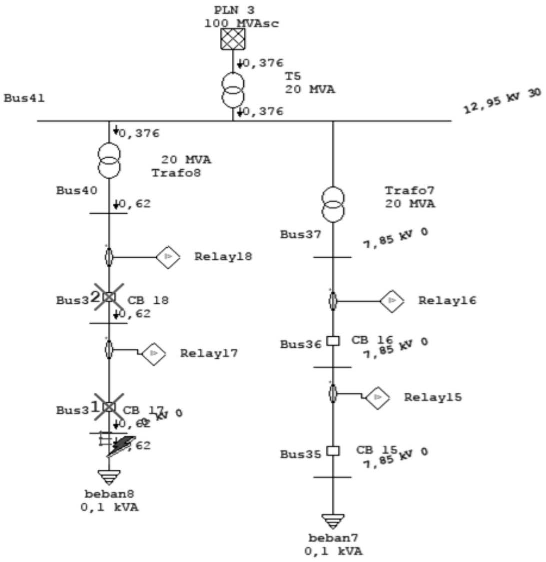

Fig. 5. Relay Coordination at Minimum Load using ETAP 12.6.1

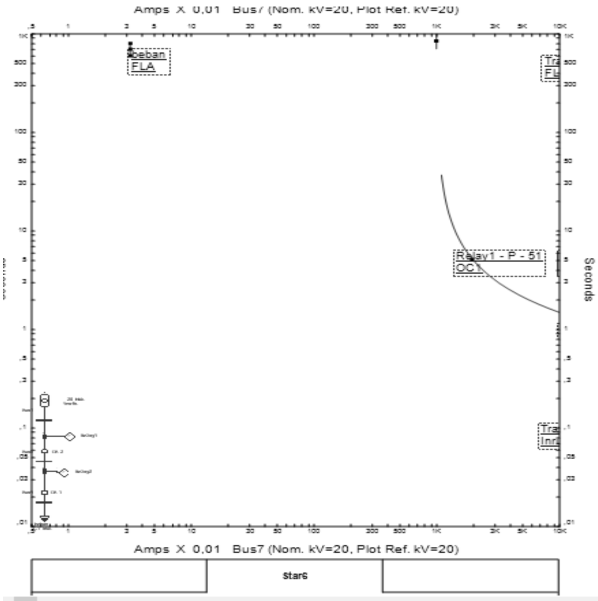

Fig. 6. Curve of Coordination Time-Current Correlation at Minimum Load

Observation of relay coordination at minimum load is doing by seeing the *time-current correlation* curve when it given a load as much 98 A at 100% coordination disctance in 3-ph on bus 3. The simulation result found that if a short circuit accour on bus 3 then relay number 17 will work to coordinate the circuit breaker (CB 17) to isolate the power system. Furthermore *relay* 18 will coordinate the CB 18 to isolate the fault system. Based on a review of the current *curve - time corelation* found that when a short circuit accour on bus 3 with 20kV then a relay coordination time is 0.5 seconds as well (still meet the standard requirement). The suggested OCR and GFR setting could be confirmed to be more effective. Finally, the resetting of OCR and GFR is applied into the distribution system in enhancing the continuity of power distrbution system at sub-station SP-2 Tanah Miring Merauke.

4.0 CONCLUSION

Short circuit simulation is given at 100 % coordination of distance with the current magnitude with 3-ph is 1086.93 A for OCR and 241.51 A with 1-ph for GFR. At the maximum load conditions at feeder SP -9 (917 A) found a setting number of OCR is 4.5 A with TMS 0.46 seconds. Other hands, the GFR setting is 4.58 A with TMS 0.17 seconds. At the minimum load condition at feeder SP-9 (324 A) found a setting number of OCR is 1.62 A with TMS 0.29 seconds. Other hands, the GFR setting is 1.62 A with TMS 0,22 seconds. At the maximum load conditions at feeder Kebun Cokelat (995 A) found a setting number of OCR is 4.97 A with TMS 0.46 seconds. Other hands, the GFR setting is 4.97 A with TMS 0.17 seconds. At the minimum load at feeder Kebun Cokelat (100 A) found a setting number of OCR is 0.5 A with TMS 0.43 seconds. Othe side, the GFR setting is 0.5 A with TMS 0,35 seconds. A maximum load level is at 1100 A while a minimum load is at 98 A. When the minimum load drop to 98 A, then OCR and GFR coordination time still remain 0.5 seconds. This analysis give insight that relays are not allowed to operate above 1100 A (maximum) and below 98 (minimum) due to if it working out of the load range then the coordination time will not meet the manual standard requirement (standard manual is ≤0.5seconds). If the load demand from costumer increase significant then the GFR and OCR setting must be adjusted.

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