An ANFIS based approach to improve the fault location on 110kV transmission line Dak Mil – Dak Nong

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Abstract

This paper provides an overview of the fault location task by single end based impedance method in Areva relay, its challenges, and describes the best established practices for an adaptive network based fuzzy inference system (ANFIS) based approach to improve the performance of the fault location on 110kV Transmission Line Dak Mil – Dak Nong in Viet Nam. It also provides details of a proven process for using magnitudes of voltages and currents from one terminal line as input data of the ANFIS. In this approach, an ANFIS was trained and tested using various sets of field data, which was obtained from the simulation of faults at various fault scenarios (fault types, fault locations and fault resistance) on Matlab/Simulink. This has been included in the personal computer as an extension of the existing methods in relay AREVA P543. The detailed explanation and results indicate that the ANFIS can determine the location of the fault upon its occurrence in order to speed up the repair service and restore the power supply.

Keywords: *Fault classification, Fault location, Transmission line, Anfis, Matlab/Simulink*

1. Introduction

Fault location is an important function of the power system. This allows improving the speed of clearing times for faults occurring at any point on the transmission line. The increased accuracy into the fault's detection and location makes it easier for maintenance, this being the reason to develop new possibilities for a precise estimation of the fault location [6].

Impedance based fault location is the most well-known technology used today to find the position of a fault in a transmission line by digital relays at either ends or dedicated fault locators [9]. They make use of the fundamental frequency voltages and the currents, and can be classified as single-ended and multi-ended methods. The one end algorithm is the simplest and does not require the communication of data between the monitoring devices located at different ends of the same transmission line. However, it is subject to several sources of error, such as the reactance effect, the line shunt capacitance, and the fault resistance value [5]. As a result, the location error of Toshiba get a maximum of ±2.5 km for faults at a distance of up to 100 km, and a maximum of ±2.5% for faults at a distance between 100 km and 250 km [15] or accurate fault location of Siemens is ≤ 2.5% of line length (without intermediate infeed) [13], or Sel is ≤ 2.5% [12], or Abb is 2.5% [1] and Areva is ≤ 2.5% [3]. Besides that, the multi-ended methods can improve upon the accuracy of single-ended methods [4]. However, the method is dependent on the available communications channel among the transmission line terminals. The communications channel is used to exchange information between each relay located at the transmission line terminal. So that it needs to process signals from multi terminals of the line and thus, larger amount of information is utilized. As a result, it is hard to apply in the high voltage transmission lines in Viet Nam

Fault location methods using traveling waves are independent of the network configuration and the devices installed in the network. These techniques are very accurate, but require high sampling rate and their implementation is more costly than the implementation of impedance based techniques [11].

On the other hand, the intelligent computational techniques such as Fuzzy Inference System (FIS), Artificial Neural Network (ANN) and adaptive network based fuzzy inference system (ANFIS) have the potential advantage over conventional techniques in significantly improving the accuracy in fault location. There has been a large number of research activities in the universities as well as research institutions to determine alternative methods to use conventional techniques for accurate location of fault in transmission and distribution lines [11]. Some of the published results of the application of ANFIS related to the improvements in fault location may be found in [2, 7, 8, 14]. However, most of results only obtained from the simulation of faults at various points of a transmission line using a computer program.

This study is organised as the follows. The next section describes the problem of fault location application on

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110kV transmission line Dak Mil – Dak Nong. In Section 3, the proposed solution for improved accuracy in fault location is presented. Section 4 analyses test results and discussion. Finally, a conclusion is given.

2. Fault location application problem on 110kV transmission line Dak Mil – Dak Nong

2.1 Basic theory for fault location on Areva relay

The relay has an integral fault locator that uses information from the current and voltage inputs to provide a distance to fault location feature. Figure 1 shows a faulted transmission line connecting two systems p and q. In order to gain a deeper perspective into the impedance method, we will first derive the equation for Vp and then, solve it for the fault location using assumption $I_F R_F$ being zero.

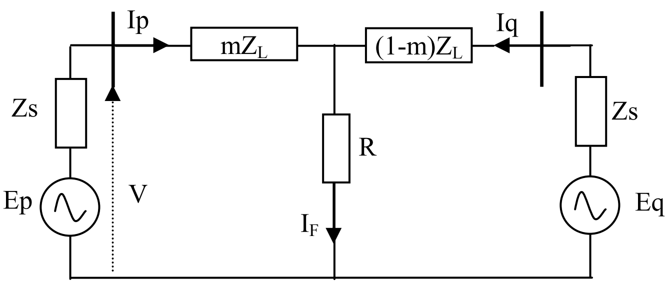

Fig.1. Two-machine equivalent circuit

From this diagram: $Vp = mIpZL + I_F R_F$ (1)

The fault location m can be found if I_F can be estimated allowing equation (1) to be solved. The fault location calculation works by [3]:

Step 1: Obtaining the vectors

The chose of different sets of vector depends on the type of fault identified by the phase selection algorithm. The calculation using equation (1) is applied for either a phase to ground fault or a phase to phase fault.

thus for an A phase to ground fault:

$IpZ_L = IaZ_L + InZ_E$ (2)

and $Vp=V_A$

and for a A phase to B phase fault:

$IpZ_L = (Ia – Ib)Z_L$ (3)

and $Vp = V_A – V_B$

Step 2: Solving the equation for the fault location

As the sine wave of I_F passes through zero, the instantaneous values of the sine waves Vp and Ip can be used to solve equation (1) for the fault location m (the term $I_F R_F$ being zero). This is determined by shifting the calculated vectors of Vp and IpZ_L by the angle (90° - angle of fault current) and then dividing the real component of Vp by the real component of IpZ_L. Therefore, from equation (1):

$m = Vp \div (IpZ_L)$ at $I_F = 0$

$= |Vp|*\sin(s\text{-}d)/(|IpZ_L|* \sin(e\text{-}d))$ (4)

Where: d is angle of fault current (I_F)
s is angle of Vp
e is angle of IpZ_L

For example, to evaluate the performance of fault locator function which is implemented on numerical relay Areva P132 (SN: 31128841) at 171 overhead line in 110kV Tuy An Substation. The settings parameter for this line are:

Length line: 30.2km

Positive sequence impedance: $Z_L = 7.48 \angle 68°$

Zero sequence compensation factors: $kZN = 0.63 \angle 11^0$

In turn, we will perform the testing of the single-ended method. Initially according to the above setting, we set parameter into relay via manual or Micom S1 Agile software. Next, using Omicron CMC 256 test set to inject the current and voltage signals into the relay for commissioning various faults (AG, BG, CG AB, BC, AC and ABC). Finally, a protection engineer reads the distance to fault display on relay' LCD and calculates error of results which are illustrated in table 1.

Table 1. Result testing on relay Areva P132

Inject current and voltage values	Lt (km)	Le (km)	Error (%)
$V_a = 0.6476\angle 0^0$; $I_a = 1\angle -72.25^0$	1.61	1.5	0.364
$V_b = 9.088\angle -120^0$; $I_b = 1\angle -192.25^0$	22.6	22.7	0.331
$V_c = 4.263\angle 120^0$; $I_c = 1\angle -14.25^0$	7.97	8.7	2.417
$V_a = 29.51\angle -47.98^0$; $I_a = 1\angle -38^0$ $V_b = 29.51\angle -72.02^0$; $I_b = 1\angle 142^0$	24.81	24.7	0.364
$V_b = 28.91\angle -176.83^0$; $I_b = 1\angle -230^0$ $V_c = 28.91\angle 176.83^0$; $I_c = 1\angle -50^0$	4.47	4.4	0.232
$V_a = 29.47\angle 48.43^0$; $I_a = 1\angle -60^0$ $V_c = 29.47\angle 71.57^0$; $I_c = 1\angle -240^0$	12.86	12.4	1.523
$V_a = 9.139\angle 0^0$; $V_b = 9.139\angle -120^0$ $V_c = 9.139\angle 120^0$; $I_a = 1\angle -60^0$ $I_b = 1\angle -180^0$; $I_c = 1\angle 60^0$	34.46	33.9	1.854

In table1, the maximum deviation of the estimated distance Le is measured from the relay and the actual fault location Lt is calculated by equation (4) and the resulting estimated error "Error" is expressed as a percentage of total line length L of that section as:

$$\%Error = \frac{|L_t - L_e|}{L} \times 100 \quad (5)$$

Reviews: Maximum error is lower than 2.5%.

2.2. Result distance to fault collection on the 110kV transmission line Dak Mil – Dak Nong

The 110kV transmission line Dak Mil – Dak Nong is located on Central Highland of Viet Nam, and serves the electric power needs in the region. This transmission line was selected because it has a large number of protection actions per year. Although most of the time, they are not permanent faults, but with successful reclosing, they become permanent ones in some points in the future because the arc passed the electrical insulator.

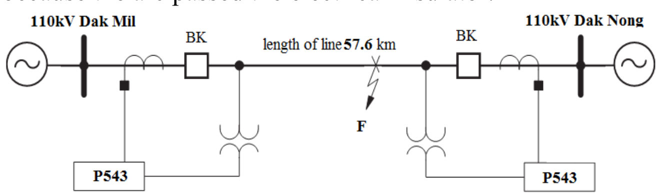

Fig.2. Schematic Diagram of 110kV Transmission Line Dak Mil – Dak Nong

In practice, the implementation of fault locator of the transmission line made with relay protection Areva P543 at each end, which shows in figure 2. The relay that desires to be checked is having the following activated settings:

Parameter setting	110kV Dak Mil Substation	110kV Dak Nong Substation
Line length[km]	57.6	57.6
Line Impedance [Ohm]	**14.97**	**19.97**
Line Angle [deg]	69	69
kZN Residual	0.62	0.62
kZN Res Angle[deg]	12	12

Fault record table collected on the relay Areva P543 and actual line from year 2012 to 2013 by Central Grid Company (CGC) in Viet Nam as shown in appendix A.

Reviews: Results of the relay's accuracy are degraded. The maximum error of Areva P543 at 110kV substation Dak Mil is 24.338% (higher than 2.5%) and Areva P543 at 110kV substation Dak Nong is 107.844% (higher than 2.5%). From the fault information above, outages can often be the signs of fault problems. There are sometimes signs that we can look for to determine if this is something that happens or perhaps a sign of things to come. There are a lot of causes but we will list some of the major ones:

- The causes that are the storm or lighting or overhead line are collided a branch or a tree by the wind. An event that is rare and difficult to deal with is the double fault (two single phases fault appear on two different phases and at two different locations).
- Line impedances based on calculation (not measurement). However, it is important for the correct configuration of the protected line to avoid miss operation of relay. Setting parameter on two relay P543 has a difference (line impedance at Dak Nong substation is 19.97 instead of 14.97). It is the major cause of very difficult for single-ended method, which precisely locates a fault on this line.
- Another important point related to the relay based on single-ended method is that it cannot be tested with actual fault that usually occurs. For instances, measurement errors in current and voltage transformers or the huge fault resistance values can also lead to the inaccuracy in estimation. Furthermore, the method just works with the simplistic models to represent the system load. The load in a practical power system does not conform to the oversimplified models leading to errors in estimation of fault location [10].

This problem can best be solved by using the ANFIS to improve accuracy in fault location which will be presented in details in section 3.

3. A solution for improving accuracy of fault location

To avoid the situation above, ANFIS can also be used as a solution. The purpose of this section is to simulate the fault occurrences on 110 kV transmission line based on the Matlab Simulink model and parameters obtained in sub section 2.2, and evaluate the performance of the ANFIS to response to those faults.

Today computer is preferred for economic as well as technical reasons. These advances of computer have been accompanied by analytical fault's causes in the field of relaying. Through the participation of researchers at Universities and industrial organizations, the theory of fault location has been placed on the intelligent computational techniques basis. Perhaps a solution lies in the software tool of computer. As long as this can be accomplished without extensive changes to the relaying system, this may be an acceptable compromise for improving accuracy in fault location.

ANFIS is a multilayer feed forward network. This architecture has five layers such as fuzzy layer, product layer, normalized layer, de-fuzzy layer and total output layer. The fixed nodes are represented by circle and the nodes represented by square are the adapted nodes. ANFIS gives the advantages of the mixture of neural network and fuzzy logic. The aim of mixing fuzzy logic and neural networks is to design an architecture which uses a fuzzy logic to show knowledge in fantastic way, while the learning nature of neural network to maximize its parameters [16].

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Based on those considerations, the question is whether an ANFIS method is possible to improve the accuracy of the fault location estimation or not. In order to use the ANFIS technique for location, the input parameters should be determined precisely. The input parameters are obtained from the numerical relay Areva P543 and the actual fault location as shown in Figure 3. The output indicates where the fault occurred and classified.

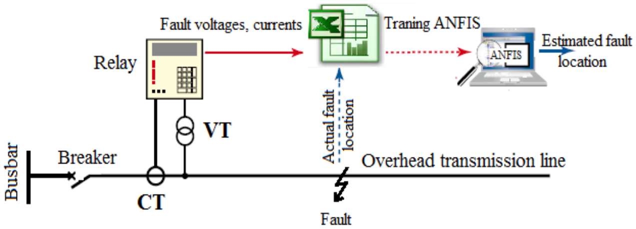

Fig.3. Application of ANFIS approach to fault location on transmission line

Due to limited available amount of practical fault data, it is necessary to generate training/testing data using simulation. To generate data for the typical transmission system, a computer program has been designed to generate training data for different faults, the power system shown in Figure 4 is simulated in MATLAB® 2012 software. It is a 110 kV, 50 Hz, 57.6km transmission line system with the parameters are as follows:

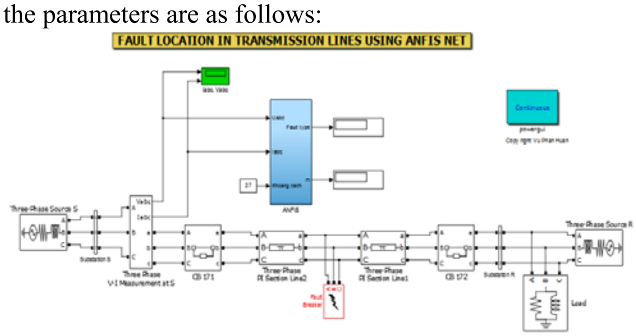

Fig.4. Power system model simulated in matlab simulink software.

1) The transmission line: three phases section line is used to represent the transmission line. Line sequence impedance:

$[R_{L1}, R_{L0}] = [0.0931, 0.1688]$ Ω/km.
$[L_{L1}, L_{L0}] = [7.7233e-04, 0.0023]$ H/km.
$[C_{L1}, C_{L0}] = [1.4386e-08, 4.831e-09]$ F/km.

2) A numeric display block to indicate the calculated random per unit length of the fault location and fault types.

3) Three phase fault block to deduce fault types and specify the parameters.

4) Three-phase measuring blocks to measure the three phase line and load current and voltage values.

5) An ANFIS has been used in this work to adapt fault locator that is located at bus S. The steps involving the neuro-adaptive learning approach are briefly presented four steps.

Step 1: Generation a suitable training data: Wide variations in fault resistance, all the ten types of short-circuit faults, loading and fault times are applied. This allows obtaining typical patterns for each fault type as shown below in Table 3.

Table 3. Parameter settings for generating training patterns.

Case No	Parameters	Set value
1	Fault type	AG, BG, CG, AB, BC, AC, ABG, BCG, ACG, ABC
2	Fault location Lf [km]	1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55
3	Loading [MVA]	1,10, 30, 50, 70
4	Fault resistance Rf [Ω]	1, 3, 5, 7, 10
5	Fault time [s]	0.07, 0.075

Step 2: Selection of a suitable ANFIS structure is performed. In this way, ten different ANFIS modules were developed to process different fault types. Single phase to ground faults have 4 inputs; double phase to ground faults and phase to phase faults have 5 inputs; and three phase fault has 6 inputs. The inputs are the magnitudes of the fundamental components (50 Hz) of three phase voltages and currents measured at the relay location. All modular ANFIS based fault location is an output that present distance to fault. In the present study, namely of available ANFIS modules based fault location of table 2 is shown in Figure 5.

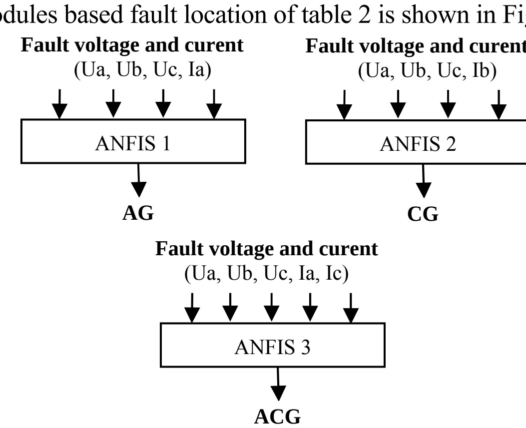

Fig.5. Block diagram of ANFIS based fault location

This work considers an initial FIS model using the options in the Generate FIS portion of the Matlab GUI. There is subtractive clustering to initialize our FIS using ANFIS. Moreover, the rule base contains the fuzzy if-then rules of Takagi and Sugeno type, in which And Method is prod, Or Method is max, Implication Method is min, Aggregation

Method is max, Defuzzification Method is wtaver (weighted average), MF's type is gaussmf, and output membership function is Linear.

Step 3: Training the ANFIS
From the analysis of ANFIS structure, an adaptive network is trained based on with off-line data. It is possible to choose the FIS model parameter optimization method which is the hybrid method, the number of training epochs (20 epochs) and the training error tolerance (0). This action adjusts the membership function parameters and displays the error plots as shown in Table 4. After the FIS is trained, it needs to be saved into the folder DakMil (combines: AnfisA.fis, AnfisC.fis, AnfisACG.fis) that uses for running the simulation.

Table 4. Structure of anfis for fault classification and location

No	Type Anfis	Anfis information			RMSE	Epochs
		Inputs	Input mfs	Output		
1	AG	4	14	1	3.01e-3	30
2	CG	4	14	1	2.82e-3	30
3	ABG	5	12	1	5.47e-4	30

Step 4: Evaluation of the trained ANFIS using test patterns until its performance is satisfactory with the proposed ANFIS tool using the Matlab/Simulink toolboxes. The simulation results are presented and discussed in Secion.4.

4. Analys Test Results and Discustion

Simulation results using data from the power system model and results compare the accuracy obtained of P543 with ANFIS are presented belows:

4.1 Test results of AG fault

The network was tested by presenting AG fault case with varying fault locations of total length, fault resistance, fault time and loading which are shown in Table 5.

Table 5. Test results of "AG" fault

No	Fault resistance [Ohm]	Loading [MVA]	Lf [km]	Le [km]	Error [%]
1	1	10	4	4.283	0.49
2	3	15	8	8.911	1.58
3	5	20	13	13.81	1.42
4	7	25	17	17.18	0.32
5	9	30	22	22.14	0.25
6	2	35	28	26.94	1.84
7	4	40	33	31.93	1.85
8	6	45	38	37.28	1.23
9	8	50	43	43.24	0.42
10	10	55	48	48.92	1.59
11	12	60	53	53.53	0.92

Reviews: The max error is 1.852% of the line length. The estimated fault location is 31.93km at (fault time is 70ms, loading is 40MVA, and fault resistance is 4Ω) as against the actual fault location 33km.

4.2 Test results of CG fault

The test results of the ANFIS based fault classifier and fault locator module for CG fault are shown in Table 6.

Table 6. Test results of "CG" fault

No	Fault resistance [Ohm]	Loading [MVA]	Lf [km]	Le [km]	Error [%]
1	1	10	4	3.86	0.243
2	3	15	8	9.53	2.656
3	5	20	13	13.26	0.451
4	7	25	17	16.74	0.451
5	9	30	22	21.58	0.729
6	2	35	28	27.33	1.163
7	4	40	33	32.95	0.087
8	6	45	38	36.88	1.944
9	8	50	43	42.78	0.382
10	10	55	48	47.37	1.094
11	12	60	53	52.11	1.545

Reviews: The estimated fault location is 9.53 at (fault time is 75ms, loading is 15MVA, and fault resistance is 3Ω) as against the actual fault location 8 km; thus, it is located accurately with max error is 2.656% of the line length.

4.3 Test results of ACG fault

The test results of the ANFIS based fault classifier and fault locator module for ACG fault are shown in Table 7.

Table 7. Test results of "ACG" fault

No	Fault resistance [Ohm]	Loading [MVA]	Lf [km]	Le [km]	Error [%]
1	1	10	4	3.886	0.197
2	3	15	8	7.736	0.458
3	5	20	13	12.65	0.607
4	7	25	17	17.45	0.781
5	9	30	22	23.04	1.805
6	2	35	28	28.64	1.111
7	4	40	33	34.05	1.822
8	6	45	38	38.81	1.406
9	8	50	43	44.37	2.378
10	10	55	48	47.37	1.093
11	12	60	53	52.34	1.145

Reviews: The estimated fault location is 44.37km at (fault time is 80ms, loading is 50MVA, and fault resistance is 8Ω) as against the actual fault location 43km; thus, it is located accurately with max error is 2.378% of the line length.

4.4 Results compare the accuracy obtained of P543 with ANFIS

In practice, current and voltage get from record of Areva P543 at 110kV substation Dak Mil that are used to investigate the effects of these factors on the performance of the proposed algorithm. The results compare the accuracy obtained of Areva P543 with Anfis that based fault classifier and fault locator module for AG, CG and ACG fault are provided in Table 8.

Table 8. Results compare the accuracy obtained of Areva P543 with ANFIS

Fault time	Fault type	Actual fault location [km]	ANFIS		P543
			Estimated fault location [km]	Error [%]	Error [%]
17/5/2013	AG	44.64	46.27	2.74	0.43
6/06/2013	ACG	26.243	27.33	1.88	4.786
10/6/2013	CG	40.029	39.23	1.38	24.34
6/9/2013	AG	27.69	26.11	2.82	2.92

Reviews: When using current and voltage from relay Areva P543, the prediction capability of ANFIS is extremely good. Output of Anfis for AG fault on 6/9/2013 is the highest error. The estimated fault location is 26.11km as against the actual fault location 27.69km; thus, it is located accurately with the max error is 2.82% of the line's length (lower than 24.34% of AREVA P543). It can be clearly seen from the test results that the proposed method, which requires the same amount of measured data, has significantly outperformed the single-ended method of Areva P543.

5. Conclusion

Currently, the single-ended method of Areva relay is employed in the majority of the relay protection (P44x, P54x, and P127). The advantages are the simplicity and the low cost because it does not need telecommunication equipment. However, the disadvantage is the loss of precision if the system is complex or the fault resistances are huge, and line parameter is incorrect. So that, with the problem of fault location on 110kV transmission line Dak Mil – Dak Nong, the paper chooses ANFIS as the best solution to satisfy its modeling needs. It allows users to improve accurately in fault location to solve the individual challenges of transmission line.

An ANFIS based approach is added as one tool to coordinate with the existing fault locator function in AREVA P543. The simulation and implementation of the ANFIS have been done by the Matlab/Simulink software program and the Power System Blockset. Different fault types have been simulated in order to evaluate the proposed approach for single phase to ground and double phase to ground fault. The obtained results clearly show that the proposed technique can accurately locate faults on transmission lines under various fault conditions.

Thus, in comparison with the Areva estimation, the ANFIS tool estimation distance to fault is more accurate as the large amount data collection from relay is applied. However, those are only improved when WAMS, SCADA, and Automation Substation are developed widely in future by means of a better use of ANFIS.

Appendix A. Results distance to fault collects on the relay and actual line from year 2012 to 2013

No	Fault time	110kV Dak Nong Substation			110kV Dak Mil Substation			Fault type
		Estimated fault location on Areva P543[km]	Actual fault location [km]	Error [%]	Estimated fault location on Areva P543[km]	Actual fault location [km]	Error [%]	
1	13/04/2012	26.72	30.8	7.083	26.46	26.8	0.5903	AG
2	11/05/2012	-1.697	12.126	23.998	44.73	45.474	1.2917	ABG
3	16/07/2012	69.6	7.482	107.844	48.98	50.118	1.9757	AG
4	17/05/2013	10.2	12.959	4.7899	44.89	44.641	0.4323	AG
5	06/06/2013	34.86	31.357	6.0816	29	26.243	4.786	ACG
6	10/06/2013	30.5	17.571	22.446	26.01	40.029	24.338	CG
7	06/09/2013	30.5	29.91	1.0243	26.01	27.69	2.9167	AG
8	08/10/2013	-2.686	28.53	54.194	29.6	29.07	0.92014	BG

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