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ELECTRICAL PROTECTION AND CONTROL SYSTEM DEVELOPMENT STEPS, AN OVERVIEW

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Abstract: A power system is not only capable to meet the present load but also has the flexibility to meet the future demands. A power system is designed to generate electric power in sufficient quantity, to meet the present and estimated future demands of the users in a particular area, to transmit it to the areas where it will be used and then distribute it within that area, on a continuous basis. Using the optimum protection and control systems with the high voltage substations are considered as the main objectives to save the system is reliable and curate operation. The protection system in high voltage substation had started by the electro–mechanical relays which improved to electrostatic relays and updated to the numerical protection relays. The switching and control of the substations had started depending on the manpower for operation and supervising the system which improved to depend on the SCADA system. This paper introduces the steps and the operation function of using the electro–mechanical, electrostatic designs and numerical relays to protect the electrical equipment in high voltage substations. Also, this paper study the improvement of the control and supervising the high voltage substations that reached now to depend on the IEC 61850 communication protocol for the optimum automation system.
Keywords: High voltage substations, Protection system, numerical relays, SAS, IEC 61850

INTRODUCTION

A protective relay is the device, which gives instruction to disconnect a faulty part of the system. This action ensures that the remaining system is still fed with power, and protects the system from further damage due to the fault. Hence, use of protective apparatus is very necessary in the electrical systems, which are expected to generate, transmit and distribute power with least interruptions and restoration time [1]. Stability in the power system is defined as the accurate operation of the system by recovering a state of operating balance after any abnormal condition such as faults, over or under voltage cases at switching time, load rejection and at loss of excitation [2].

Protection relays, are the important characteristic of power system protection helps to isolate the faculty part of the electrical system [3]. However, it is important for this relay to possess certain qualities as dependability and selective. The relay receives information regarding the network mainly from the instrument transformers (voltage and current transformer), detects an abnormal condition by comparing this information to preset values, and gives a tripping command to the circuit breaker when such an abnormal condition has been detected [4][5].

Protective relays (or multifunctional devices) are devices that permanently compare the electrical variables of networks (such as current, voltage, frequency, power, and impedances) with predetermined values, and then automatically emit orders for action (usually the opening of a circuit–breaker) or give off an alarm when the monitored value goes above the threshold [6–7]. The relay may also be operated by an external tripping signal; either from other instruments, from a SCADA master, or by human intervention.

The development of modern science and technology, especially electronic and computer technology, promoted the development of relay technology, such as materials, components and the manufacturing process of the hardware structure of relay protection device. At the same time, great theoretical progress had been made in the relay protection software, algorithms, etc. As shown in figure (1), the progress in modern technology stimulates the development in power system protection.

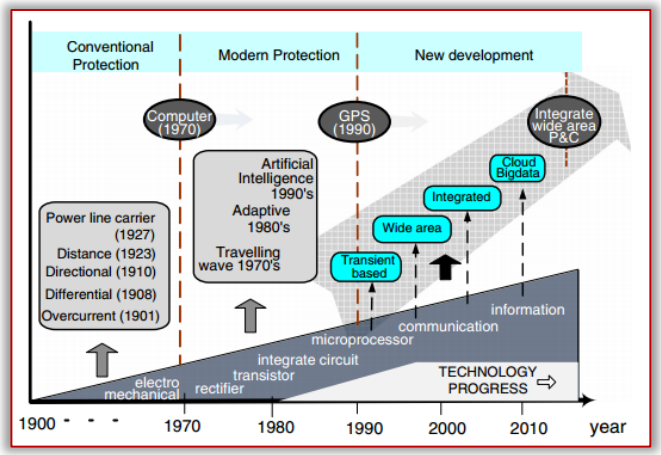


Figure 1. History of protection system development.

In the last century from the emergence of protection to the end of the 1990s, the relay protection had gone through a number of development stages, migrating from electro–

mechanical to semiconductor, and subsequently to integrated circuit and microprocessor technologies.

Today, microprocessor–based digital and numeric relays are replacing conventional relays in all areas of power system protection [8]. This paper discusses the importance of using the protection system with the electrical power system for saving the stability power system. Also, this paper discusses the development steps of the protection and control system, with focusing on the numerical relays.

BASIC COMPONENTS OF PROTECTION SYSTEM

Protection of any distribution system is a function of many elements and this manual gives a brief outline of various components that go in protecting a system. Electrical faults usually occur due to breakdown of the insulating media between a live conductor and earth, this breakdown may be caused by any one or more of several factors, mechanical damage, overheating, voltage surges (caused by lighting or switching), ingress of a conducting medium ionization of air, deterioration of the insulating medium due to an unfriendly environment or old age, or misuse of equipment.

Fault current release an enormous amount of thermal energy, and if not cleared quickly, may case fire hazards, extensive damage to equipment and risk to human life. Some of abnormal of the power system are; over voltage, over loads, unbalanced operation power swings, transformer inrush current faults, short circuits, short circuits with ground, open conductors [9–10]. Figure (2) shows the element of protection system. Following are the main components of protection.

- Fuse is the self–destructing one, which carries the currents in a power circuit continuously and sacrifices itself by blowing under abnormal conditions. These are normally independent or stand–alone protective components in an electrical system unlike a circuit breaker, which necessarily requires the support of external components.
- Accurate protection cannot be achieved without properly measuring the normal and abnormal conditions of a system. In electrical systems, voltage and current measurements give feedback on whether a system is healthy or not. Voltage transformers and current transformers measure these basic parameters and are capable of providing accurate measurement during fault conditions without failure.
- The measured values are converted into analog and / or digital signals and are made to operate the relays, which in turn isolate the circuits by opening the faulty circuits. In most of the cases, the relays provide two functions viz., alarm and trip, once the abnormality is noticed. The relays in olden days had very limited functions and were quite bulky. However, with advancement in digital technology and use of microprocessors, relays monitor various parameters, which give complete history of a system during both pre–fault and post–fault conditions.
- The opening of faulty circuits requires some time, which may be in milliseconds, which for a common day life could be insignificant. However, the circuit breakers, which are used to isolate the faulty circuits, are capable of carrying these fault currents until the fault currents are totally cleared. The circuit breakers are the main isolating devices in a distribution system, which can be said to directly protect the system.
- The operation of relays and breakers require power sources, which shall not be affected by faults in the main distribution. Hence, the other component, which is vital in protective system, is batteries that are used to ensure uninterrupted power to relays and breaker coils.

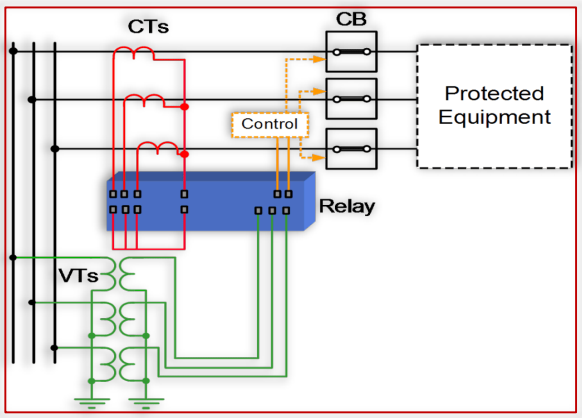


Figure 2. Elements of protection system.

BASIC REQUIREMENTS OF PROTECTION

These requirements are necessary, firstly for early detection and localization of faults, and secondly for prompt removal of faulty equipment from service.

Sensitivity, selectivity and speed are terms commonly used to describe the functional characteristics of any protective–relaying equipment [9].

In order to carry out the above duties, protection must have the following qualities [10]:

— Selectivity: To detect and isolate the faulty item only.
— Stability: To leave all healthy circuits intact to ensure continuity or supply.
— Sensitivity: To detect even the smallest fault, current or system abnormalities and operate correctly at its setting before the fault causes irreparable damage.
— Speed: To operate speedily when it is called upon to do so, thereby minimizing damage to the surroundings and ensuring safety to personnel.

To meet all of the above requirements, protection must be reliable which means it must be:

— Dependable: It must trip when called upon to do so.
— Secure: It must not trip when it is not supposed to.
— Reliability: That protective–relaying equipment must be reliable is a basic requirement.

When protective relaying fails to function properly, the allied mitigation features are largely ineffective.

DEVELOPMENT STEPS OF PROTECTION RELAYS

Relays are the electrical devices that accept current or voltage signals in an input circuit as a prompt to switch open or close another circuit or pilot device. In this way, relays are switches that are controlled by some other input. The output is to trigger a predictable state change in the connected system. The point of a relay is to use a small amount of power to switch to a large amount of power.

Relays operate in industrial machines, plant equipment, and even consumer–grade vehicles and appliances employing electrical power and control signals [1–4]. Figure (3) shows operating mechanism of electromechanical relay.

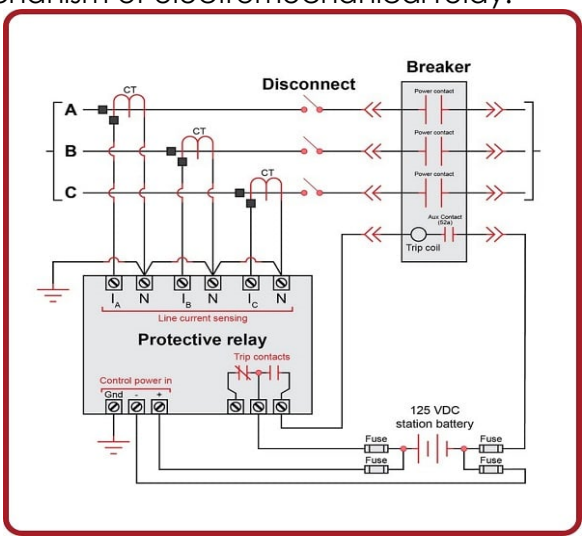


Figure 3. Operating mechanism of electromechanical relay

ELECTROMECHANICAL RELAYS

Electromagnetic relays are those relays which operates on the principle of electromagnetic attraction. It is a type of a magnetic switch which uses the magnet for creating a magnetic field. Which controls opening and closing of the relay. Figure (4) shows the electromechanical relay design.

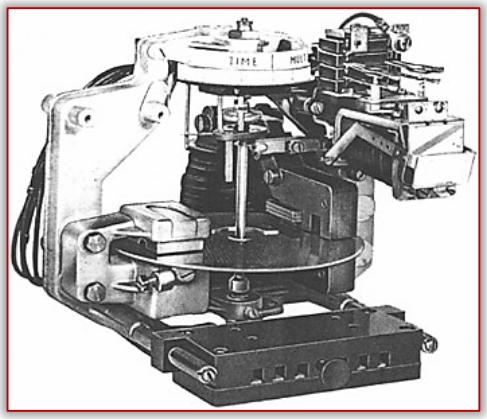


Figure 4. Electromechanical relay.

ELECTROSTATIC RELAY

The relay which does not contain any moving parts is known as the static relay. In such type of relays, the output is obtained by the static components like magnetic and electronic circuit etc as shown in figure (5). The relay which consists static and electromagnetic relay is also called static relay because the static units obtain the response and the electromagnetic relay is only used for switching operation. Figure (6) shows the electrostatic relay operation logic. The advantage of using the electrostatic relays as compared with the electromechanical relays can be summarized as:

— The static relay consumes very less power because of which the burden on the measuring instruments decreases and their accuracy increases.
— The static relay gives the quick response, long life, high reliability and accuracy and it is shockproof.
— The reset time of the relay is very less.
— It does not have any thermal storage problems.
— The relay amplifies the input signal which increases their sensitivity.
— The chance of unwanted tripping is less in this relay.
— The static relay can easily operate in earthquake–prone areas because they have high resistance to shock.

Figure 5. Electrostatic relay.

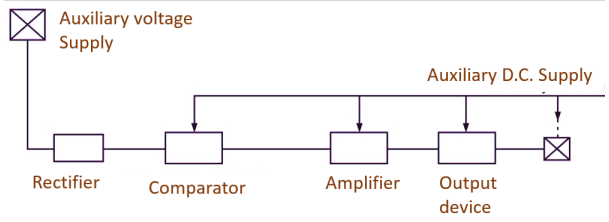


Figure 6. Operation logic of electrostatic relay

The Limitation of Electrostatic Relay can be summarized as:

— The components used by the static relay are very sensitive to the electrostatic discharges. The electrostatic discharges mean sudden flows of electrons between the charged objects.
— The relay is easily affected by the high voltage surges. Thus, precaution should be taken for avoiding the damages through voltage spikes.
— The working of the relay depends on the electrical components.
— The relay has less overloading capacity.
— The static relay is more costly as compared to the electromagnetic relay.
— The construction of the relay is easily affected by the surrounding interference.

NUMERICAL RELAYS

The Numerical protection relay is a type of an electronic switch that opens or close the circuit contacts by using electronic component without any mechanical operation, as shown in figure (7).

Figure 7. Numerical protection relay

The Solid–State Relay provides a high degree of reliability, long life and reduced electromagnetic interference (EMI), (no arcing contacts or magnetic fields), together with a much faster almost instant response time, as compared to the conventional electromechanical relay. Also, the input control power requirements of the solid–state relay are generally low enough to make them compatible with most IC logic families without the need for additional buffers, drivers or amplifiers. However, being a semiconductor device, they must be mounted onto suitable heatsinks to prevent the output switching semiconductor device from overheating [10–12]. As shown in figure (8) for the input output module.

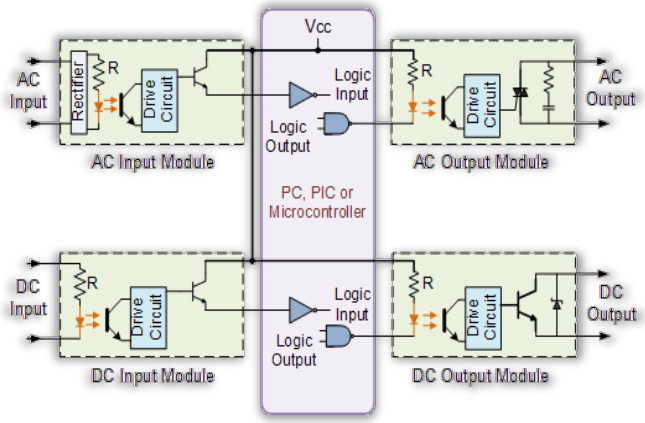


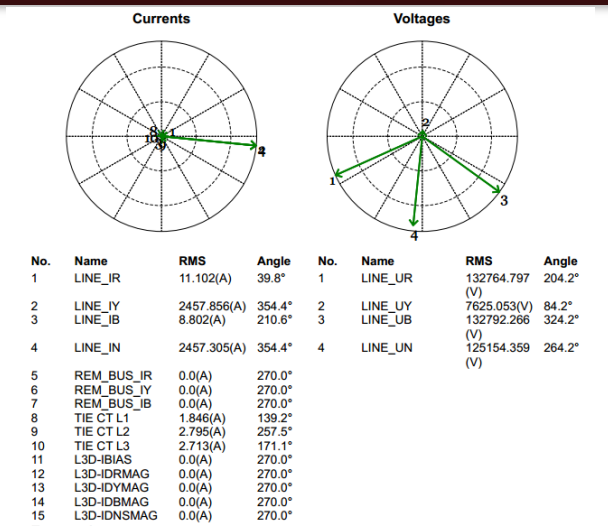
Figure 8. Modular Input/Output Interface System.

IMPORTANCE OF NUMERICAL RELAYS

With the fast progress in high–speed communication network and information technology, there were significant developments in power system protection found by the numerical relays that can be summarized as:

— Numerical relays are requiring low maintenance.
— The relay has fast response time.
— They decrease the burden on the instrument transformer.
— Simple to configure or reconfigure.
— Can communicate with the computer.
— It can find multi–function in one relay.
— It can save any disturbance in the power system.
— It can show the loads in the system.
— It can send the system data and the signals to the remote control.

The event recorder in the numerical relays is considered as one of the main advantage points in the numerical relays. Figure (9) and figure (10) shows the disturbance recorder retrieved from numerical relay.



No.	Name	RMS	Angle	No.	Name	RMS	Angle
1	LINE_IR	11.102(A)	39.8°	1	LINE_UR	132764.797 (V)	204.2°
2	LINE_IY	2457.856(A)	354.4°	2	LINE_UY	7625.053(V)	84.2°
3	LINE_IB	8.802(A)	210.6°	3	LINE_UB	132792.266 (V)	324.2°
4	LINE_IN	2457.305(A)	354.4°	4	LINE_UN	125154.359 (V)	264.2°
5	REM_BUS_IR	0.0(A)	270.0°				
6	REM_BUS_IY	0.0(A)	270.0°				
7	REM_BUS_IB	0.0(A)	270.0°				
8	TIE CT L1	1.846(A)	139.2°				
9	TIE CT L2	2.795(A)	257.5°				
10	TIE CT L3	2.713(A)	171.1°				
11	L3D-IBIAS	0.0(A)	270.0°				
12	L3D-IDRMAG	0.0(A)	270.0°				
13	L3D-IDYMAG	0.0(A)	270.0°				
14	L3D-IDBMAG	0.0(A)	270.0°				
15	L3D-IDNSMAG	0.0(A)	270.0°				

Figure 9. Disturbance recorder part–1 of faut.

Channel Number	Name	Status	Time
21	DEF FW START	On	5/3/2023 1:15:06.533 PM
46	DEF START	On	5/3/2023 1:15:06.533 PM
92	DEF-ST FW	On	5/3/2023 1:15:06.533 PM
50	PHS STFW Y	On	5/3/2023 1:15:06.536 PM
52	PHS STFWN	On	5/3/2023 1:15:06.536 PM
90	DIST-ST FW	On	5/3/2023 1:15:06.539 PM
7	ZONE-2 START	On	5/3/2023 1:15:06.543 PM
9	ZONE-3 START	On	5/3/2023 1:15:06.543 PM
5	ZONE-1 START	On	5/3/2023 1:15:06.546 PM
6	ZONE-1 TRIP	On	5/3/2023 1:15:06.546 PM
82	DIST ST L2	On	5/3/2023 1:15:06.546 PM
17	94F2 OPERATED	On	5/3/2023 1:15:06.562 PM
50	PHS STFW Y	Off	5/3/2023 1:15:06.573 PM
52	PHS STFWN	Off	5/3/2023 1:15:06.573 PM
82	DIST ST L2	Off	5/3/2023 1:15:06.573 PM
21	DEF FW START	Off	5/3/2023 1:15:06.574 PM
92	DEF-ST FW	Off	5/3/2023 1:15:06.574 PM
90	DIST-ST FW	Off	5/3/2023 1:15:06.576 PM
9	ZONE-3 START	Off	5/3/2023 1:15:06.583 PM
46	DEF START	Off	5/3/2023 1:15:06.583 PM
5	ZONE-1 START	Off	5/3/2023 1:15:06.586 PM
6	ZONE-1 TRIP	Off	5/3/2023 1:15:06.586 PM
7	ZONE-2 START	Off	5/3/2023 1:15:06.589 PM
17	94F2 OPERATED	Off	5/3/2023 1:15:06.609 PM

Figure 10. Disturbance recorder part–2 of fault.

IEC 61850 TRANSMITTING DATA TO CONTROL CENTRE

One of the main important points of using the numerical relays to add the availability to control the high voltage substation from remote. These benefits saved the cost and found the accurate recording and supervising the substations as compared with the system that depends on the man power.

Main reason of developing IEC 61850 was to create an international standard that will ease the communication between substation devices using Logical Nodes (LN) and data classes to address the issues regarding the interoperability and interchangeability, which instead of a configured IED description (CID) file [11]. IEC 61850 protocol is starting by translating the protection function into the relay to the Manufacturing Message Specification (MMS) data that able to uses for the roots in addressing data and to report digital statuses and simulated alarm inputs.

Figure (11) shows the mapping of the multi–function protection relay SEL–411L into the protection logic to the MMS data which known in this relay type by "PSV**", where "**" means the MMS number which can introduce in the SAS configuration with IEC 61850 as the actual operation function. Also, figure (12) shows the mapping of MICOM–P546 multi–function protection relay, which translating the MMS as a virtual output into the relay that translating in the SAS configuration to the programmed protection function [12].

```
1 ###################### SAS SIGNAL CONFIGURATION ################
2 PSV02 := Z1T AND NOT VT_FFAL # Z1 TRIP
3 PSV03 := Z2T AND NOT VT_FFAL # Z2 TRIP
4 PSV04 := Z3T AND NOT VT_FFAL # Z3 TRIP
5 PSV05 := Z4T AND NOT VT_FFAL # Z4 TRIP
6 PSV06 := (Z1T OR Z2T OR Z3T) AND NOT VT_FFAL AND PHASE_A # DIST PHASE A TRIP
7 PSV07 := (Z1T OR Z2T OR Z3T) AND NOT VT_FFAL AND PHASE_B # DIST PHASE B TRIP
8 PSV08 := (Z1T OR Z2T OR Z3T) AND NOT VT_FFAL AND PHASE_C # DIST PHASE C TRIP
9 PSV09 := (87OP AND PHASE_A) OR 87LA # DIFF PHASE A TRIP
10 PSV10 := (87OP AND PHASE_B) OR 87LB # DIFF PHASE B TRIP
11 PSV11 := (87OP AND PHASE_C) OR 87LC # DIFF PHASE C TRIP
12 PSV12 := VT_FFAL # BINARY INPUT FOR VT MCB TRIP
13 PSV13 := ILOP # INTERNAL VT FUSE FAIL
```

Figure 11. Converting the protection function to the MMS data object into SEL–411L IED.

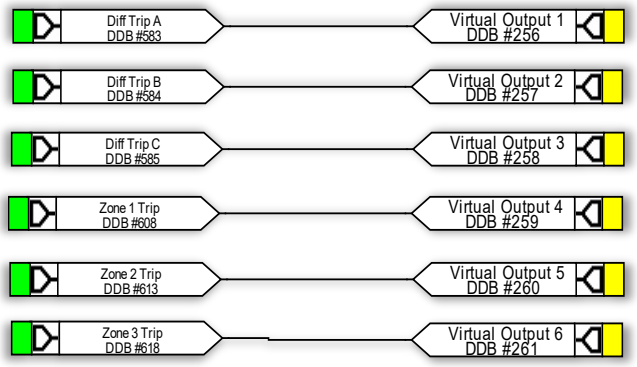


Figure 12. Converting the protection function to the MMS data object into MICOM P546.

Table 1. The text of the protection function in figure (11) and figure (12)

No.	Abbreviation	Protection function text
1	Z1PT	[SEL–411L] Distance protection first zone phase–phase trip
2	Z1GT	[SEL–411L] Distance protection first zone phase–ground trip
3	Z2PT	[SEL–411L] Distance protection second zone phase–phase trip
4	Z2GT	[SEL–411L] Distance protection second zone phase–ground trip
5	Z3PT	[SEL–411L] Distance protection third zone phase–phase trip
6	Z3GT	[SEL–411L] Distance protection third zone phase–ground trip
7	87OP	[SEL–411L] Line differential trip
8	87LA	[SEL–411L] Line differential trip phase–A
9	87LB	[SEL–411L] Line differential trip phase–B
10	87LC	[SEL–411L] Line differential trip phase–C
11	Diff Trip A	[MICOM–P546] Line differential trip phase–A
12	Diff Trip B	[MICOM–P546] Line differential trip phase–B
13	Diff Trip C	[MICOM–P546] Line differential trip phase–C
14	Zone 1 Trip	[MICOM–P546] General distance protection first zone trip
15	Zone 2 Trip	[MICOM–P546] General distance protection second zone trip
16	Zone 3 Trip	[MICOM–P546] General distance protection third zone trip

Table (1) shows the text of the protection function in figure (11) and figure (12). Once the protocols are created the next step is to map them to the data models and services of the standard, the HMI inside the substation can show the unlimited alarms and status. In another hand, to decrease the alarms in the control centre which shows a lot of substation alarms, it's possible by the IEC 61850 to compress the

matched alarms to one address. The ring links between the HV substations are depending on the Ethernet cables to transmit the digital code address to reach the control centre throw two main and backup channels.

CONCLUSIONS

A power system is designed to generate electric power in sufficient quantity, to meet the present and estimated future demands of the users in a particular area, to transmit it to the areas where it will be used and then distribute it within that area, on a continuous basis. By using the suitable control system for enhancing the power system quality to save the system in the safe operation and control, also to support the operation and maintenance team to normalize the system in very low time after interruption or any abnormal condition.

In this presentation we discussed the development steps of the protection system starting from electromagnetic relay to electrostatic relay and the numerical protection relay.

Finally, from this paper, its recommended to the power system designer to uses the numerical relays, due to these relays can protect various components such as feeder, Motor, Generator, Transmission line, Transformers and Busbars.

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