IAIS concept for intelligent substations

Substations based on the IAIS (Intelligent Air-Insulated Substation) concept are built on small sites, require a minimum of maintenance, and exhibit high availability and reliability. In addition, advanced planning and engineering tools shorten the project lead times for the substations. At the center of the IAIS concept is a high-speed process bus for the communication between the switchgear and the control system. The concept was developed to meet the changing needs of the electric power industry as it adapts to market deregulation.

The electric power industry is going through a period of intense restructuring as a result of privatization, relaxed state control and market pressure on costs. This is having an effect on the way equipment is procured. The trend is away from specifications that detail the exact requirements the individual components must satisfy towards a more general catalogue of needs in terms of function, environment, availability, maintenance and so on. To take account of the changing situation, ABB developed the Intelligent Air-Insulated Substation, or IAIS. The concept offers compact substations with outdoor switchgear in the 110 to 550 kV range.

The IAIS concept is the result of close collaboration between Swedish-based ABB Substations, ABB Switchgear, ABB Network Partner, ABB Power Systems and ABB Transformers. At its center is a high-speed process bus over which the switchgear communicates with the control system, and vice versa. In addition, the high-voltage switchgear has multiple functions and integrated devices for transmitting digital signals. The system apparatus is further equipped with monitoring facilities.

The IAIS concept has several important advantages over conventional substations:

- Substation sites are 30 to 50 percent smaller in size due to the integrated multiple functions **1** and the smaller current transformers that are used. Since fewer disconnectors are needed, considerably fewer foundations, mechanical structures and high-voltage joints are necessary. Compliance with all the required safety clearances is nevertheless ensured **2**.
- Maintenance is reduced due to scheduled, routine maintenance work being replaced by 'Maintenance on Demand'. Numerical technology ensures stable, reliable functions and allows continuous self-monitoring of the overall system - from the switchgear components through the bus and control modules to the station control system. The number of high-voltage connections are reduced by 50 percent and control cables by 85 percent. This and a drastic reduction in disconnector maintenance translates into considerably lower service and maintenance costs.
- Availability is increased as a result of continuous trend monitoring, which reduces the risk of unforeseen operating disturbances, and easy replacement of defective units, which shortens downtimes. Also, the numerical technology with self-diagnostics facility eliminates regular testing of the protection equipment. Calculations show that non-availability often decreases by a power of ten even for simple busbar configurations.
- Product lead times are shorter and customers can have substations up and running faster. Groups of components are tested together before assembly. Less time is required for on-site construction, assembly and commissioning than with conventional substations. The time for control cable work is reduced by 85 percent.
- Safety is improved in spite of the more compact substation layout. Compliance with safety regulations is at least as good as with earlier designs. Technical innovations moreover shorten the length of time personnel spend in the substation. Use of fiber-optic cables in place of copper conductors reduces the danger of short circuits in the secondary equipment and virtually eliminates the risk of fire spreading through the control cable installation. Conventional current transformers and their 1 ampere or 5 ampere secondary circuits are no longer needed. Personnel safety in the station is improved by all of these measures.

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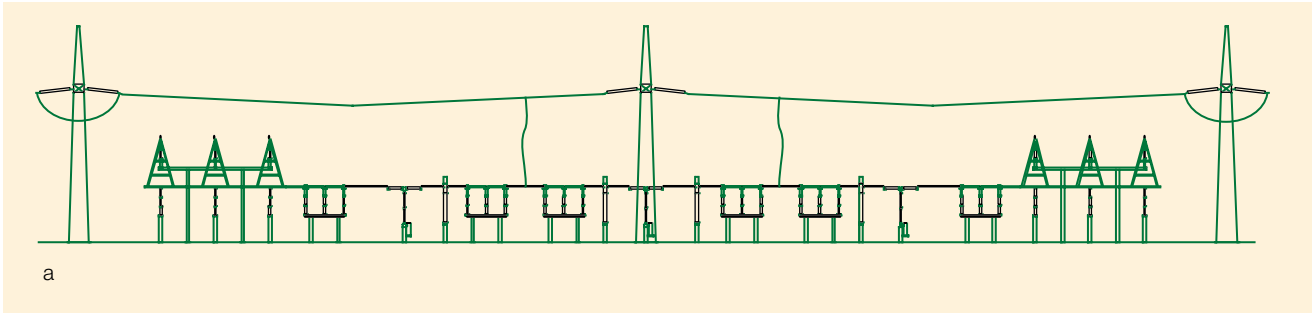


Comparison of a conventional 420-kV switchyard in a 1½-breaker ring bus arrangement (a) and the same substation based on the IAIS concept (b). The number of components is considerably reduced in the latter case. **1**

IAIS – complete, integrated and coordinated

High-speed process bus for data signal transmission

Communication, which is digital, is over a fiber-optic, deterministic process bus in redundant mode **3**. The signals are digitized before they leave the primary equipment. Measurement, protection and substation control signals are all transmitted over the process bus. The output stage of the main apparatus is in each case a solid-state switch with continuous self-monitoring facility.

During commissioning, the overall system is tested with the help of special software which checks the data sent to and from the bus. This allows all of the functions to be verified, settings checked and all tolerances tested.

Monitoring of the total system takes place continuously during operation. Any disturbances that occur are displayed and recorded. The principle of 'Maintenance on Demand' has been adopted, ie maintenance is carried out in the event of an alarm, abnormal switchgear behaviour, or when the equipment signals that maintenance is needed.

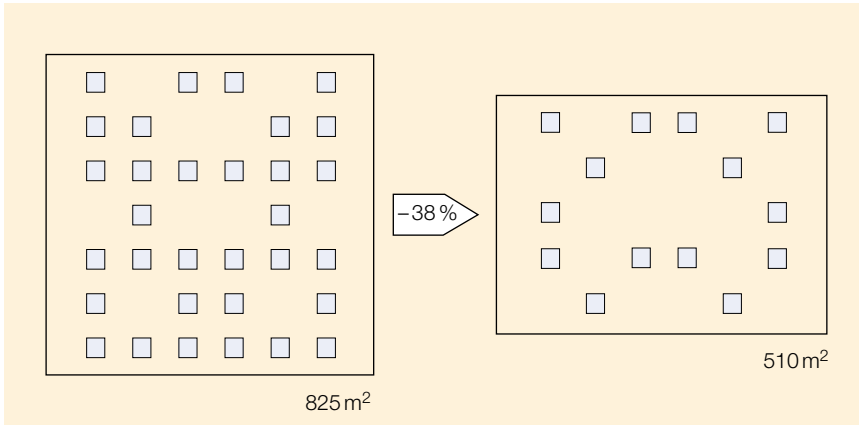
Components that meet the system requirements

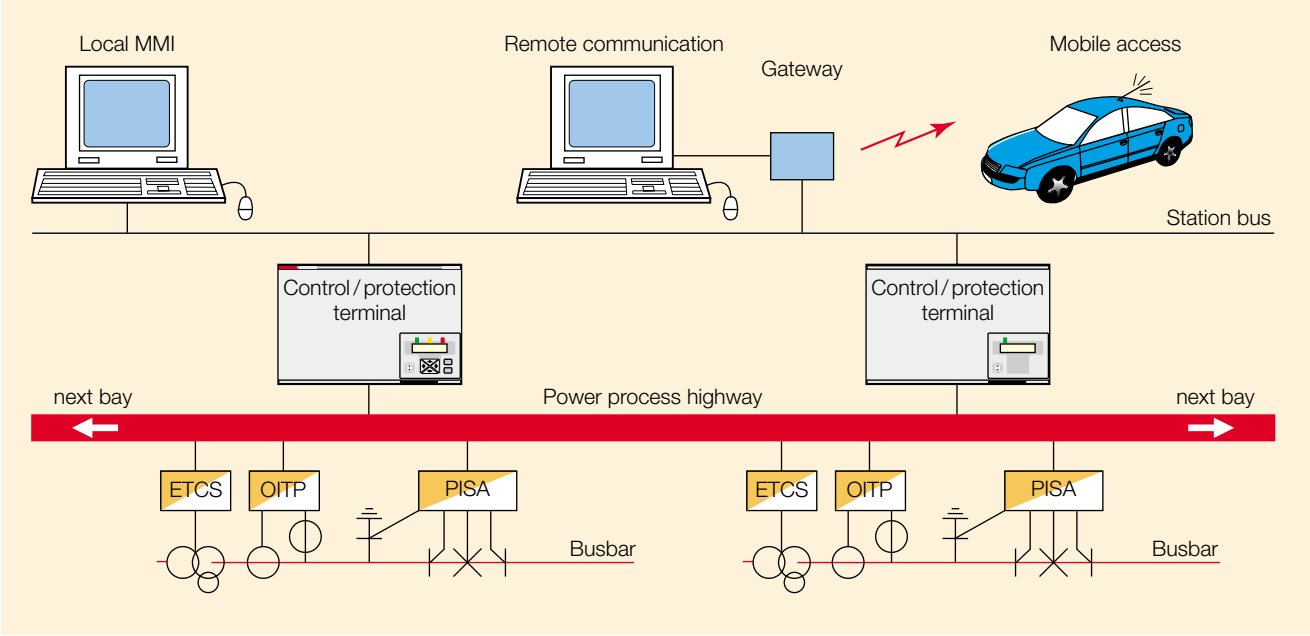
Conventional substations consist of separate switchgear and control system components which are not always matched exactly to one another. This requires auxiliary apparatus, for which additional foundations, high-voltage connections, control system cable and relays are needed. These all take up extra space. In addition, the busbars have to be designed for such a layout.

The IAIS concept, on the other hand, is based on simple busbar configurations and drawout switching modules with a disconnector function. Where appropriate, modern current and voltage sensors have been integrated in the high-voltage apparatus. These measures have significantly reduced the space needed.

The disconnector function has been substantially improved. The underlying principle is that the permanently installed

The IAIS concept reduces the site area and number of foundations needed for a substation, here for a 145-kV switchyard with three switchbays. **2**





The process bus carries all of the information transmitted between the HV substation and the control system. Redundant systems with two buses are also possible. **3**

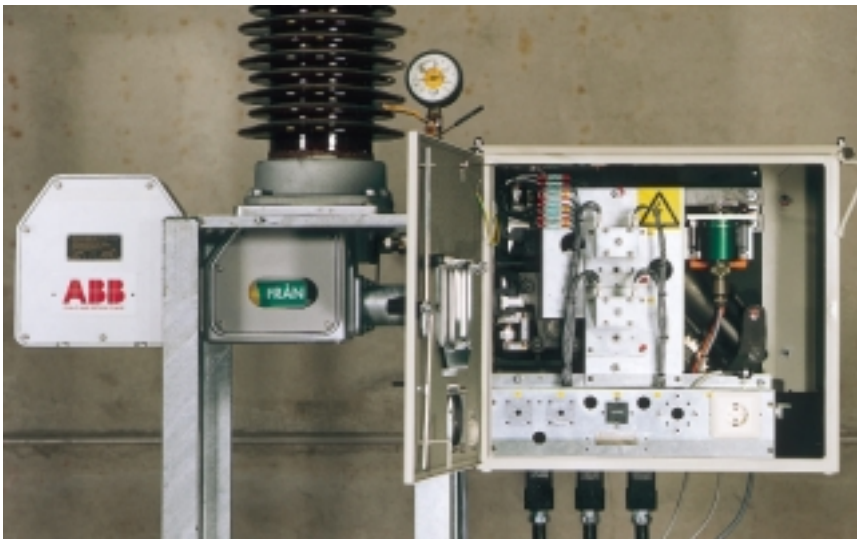
OITP *Optical instrument transducer platform* PISA *Process interface, sensors and actuators*

disconnectors shall be virtually maintenance-free over a 30-year period. Where at all possible, the disconnectors are integrated in a switching module together with the circuit-breaker and other equipment, and removed for maintenance.

The voltage and current sensors make use of proven measurement principles, combined with state-of-the-art signal processing and data transmission. The current sensors are mounted on high-voltage connectors or are integrated in the circuit-breaker. Mounting is possible on either or both sides of the circuit-breaker.

The voltage sensors are often installed together with an earthing switch. Combined current and voltage sensors are also possible, for example to create sensor units for power measurement modules.

LTB-Compact switching module with breaker operating mechanism and the unit for distributed control and communication **4**



Compact switching modules with monitoring and bus communication functions

The new high-voltage switchgear is the result of further development of proven apparatus in combinations designed for simple busbar configurations. The switchgear features new monitoring functions as well as a PISA unit for communication over the process bus **4**. It is equally well-suited for new substations and substation upgrades.

The *LTB-Compact switching module* for 110–245 kV has a truck-mounted part with a type LTB circuit-breaker **5** in triple-pole configuration. There are two disconnector (truck) contacts and two fixed, maintenance-free, contacts for each phase. The disconnection is effected by a standard disconnector operating mechanism, which separates the

130-kV switchyard with drawout LTB-Compact switching module (foreground) **5**

movable and fixed contacts by pulling out the truck-mounted unit on rails. The entire module is type-tested. All the mechanical and electrical tests specified in the standards for disconnectors and circuit-breakers are carried out.

Maintenance can be carried out on the LTB-Compact module without having to take the busbar out of operation. The fixed contacts require no maintenance. On-site repairs are unnecessary, since a failed unit can be easily replaced. Availability is therefore higher than with similar configurations featuring separate components.

The *HPL-Compact switching module* for 275–550 kV consists of a type HPL circuit-breaker, fitted with a pantograph disconnector and an earth switch on each side **6**. The current sensors are mounted direct on the breaker poles. All of the units are proven in service.

When maintenance is to be carried out, the module can be taken out of service simply by opening the circuit-breaker and its disconnectors. The work can be performed either locally or in a special repair bay. If required, a replacement module can be placed in service for the duration of the maintenance. All three poles of a module can be replaced in less than 8 hours.

The switching duties of a disconnector cannot always be handled by drawout circuit-breakers. Consequently, ABB developed *LTDS-Compact*, a gas-insulated disconnector for 110–245 kV **7**. This is especially well-suited for applications requiring high availability, long lifetime and compactness. Benefits of the type LTDS disconnector include:

HPL-Compact switching module, designed for 420 kV **6**

The LTDS-Compact gas-insulated disconnector also serves as a post insulator. **7**

- Inspection is only required at 15-year intervals.
- Commutation at higher currents is possible should service conditions change.
- Space requirements are minimized.
- The disconnector doubles as a post insulator.

Earthing switches ensure that there is no danger to personnel when work is being carried out in the substations, for example due to maloperation of equipment. A range of earthing switches is available that includes units rated at 110 to 550 kV for installation anywhere in the substation **8**. No additional foundations or mechanical structures are necessary.

Reliable self-diagnostics

High reliability is ensured on the one hand by high quality during the design and production phases, and on the other by monitoring functions which detect latent faults.

To this end, the new switchgear features advanced electromechanical self-diagnostics. This facility not only indicates absolute values and evolving trends but also tells the control room personnel the best time for carrying out maintenance. Trouble-shooting, ie fault location and analysis, can be carried out either from the central control desk or from a service center with PC and mobile phone. Operating as well as maintenance personnel are therefore able to take proper action at an early stage, allowing the number of routine overhauls and preventive maintenance work to be substantially reduced.

Each switch operating mechanism is fitted with one or two PISA units for communication, actuation and monitoring. The same units also store general information and the pre-history of the switchgear, for example:

- Spring tensions and charging times
- Number of switching operations
- Ten most recent motion/time curves
- SF_6 gas density readings and trends

Digital optical current and voltage sensors

Currents and voltages are measured by the DOIT[1)] system **9**. Measurement is by conventional means, but the data signals are transmitted over fiber-optic wires. This allows much smaller instruments to be used and considerably simplifies the HV insulation. The communication interface between the sensor and process bus transmits the measured data in one direction and simultaneously supplies energy in the other to the optical instrument transducers (via laser energy beams) **10**.

Due to the use of digital signal transmission, the overall accuracy depends on

[1] DOIT = Digital Optical Instrument Transformer

Earthing switch, here mounted on a 145-kV voltage transformer **8**

just the measurement accuracy of the sensors, which normally corresponds to class 0.2. The subsequent numerical calculation has no adverse effect on the overall system accuracy, which is therefore considerably better than with conventional measuring systems.

The current value is measured with the help of a magnetic current transformer with anti-remanence core. After sampling and digitizing, the current value is transmitted in the form of light pulses over a fiber-optic link to the OITP (Optical Instrument Transducer Platform) 11. This not only improves the dynamic response and saturation properties but also makes standardization easier than with traditional current transformers.

The technology is proven in the field, having been used successfully by ABB for a decade. More than 700 units are in operation today. Because of their low weight and small size, the sensors can easily be integrated in circuit-breakers or in other apparatus. The optical fibers are embedded in polymeric insulators, which are either mounted separately or integrated in other insulators.

A capacitor voltage divider is used to measure the voltage, the values being sampled and then digitized for transmission over a fiber-optic link to the OITP. The transfer function that results is better than with conventional voltage transformers. The risk of ferro-resonance is also eliminated.

An 'energy measuring module', consisting of combined current and voltage sensors and a signal processing unit which sends its output signals direct to standard electricity meters, ensures a system accuracy which is better than with traditional measuring arrangements.

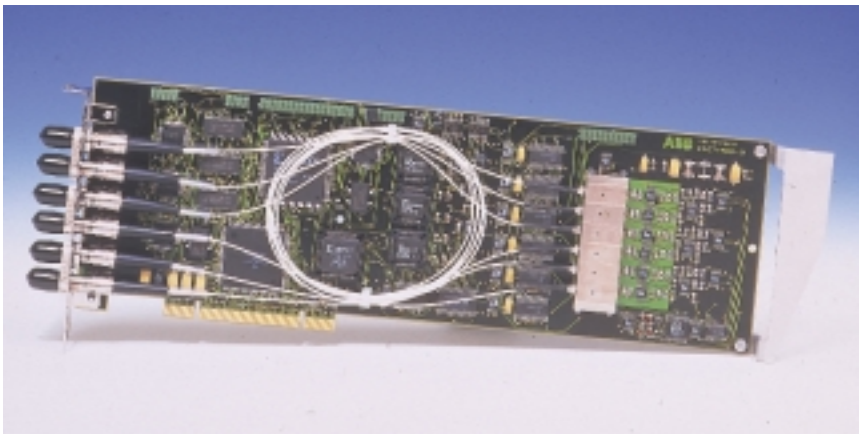
Power transformers with improved monitoring functions

Power transformers based on the IAIS concept are equipped with an electronic control unit which records every detail of their operating behaviour 12. This allows a prediction of how overloading in certain situations will affect the lifetime of the unit.

The control unit processes the standard data received from the temperature sensors, pressure monitors, Buchholz relays, etc. In addition, three

A DOIT current transformer mounted on a 420-kV circuit-breaker of type HPL 9

Interface printed-circuit board for 6 sensors of type DOIT 10



new monitoring functions are provided:

- *Partial discharge measurement*; measurement is continuous and registers even very low partial discharge values. The trend curve is stored and the unit alarm level is adapted to each application.
- *Tap-changer performance*; the acoustic 'pattern' of the tap-changer drive is compared with the original values, the alarm and interlocking system being activated when deviations occur. The system distinguishes automatically between breakdowns and disturbances which are due to wear.
- *Transformer oil quality check*; samples are taken every 12 hours in order to check the concentrations of hydrogen, carbon monoxide and a mixture of methane and ethane. A warning is given if the specified levels are exceeded.

Control and protection equipment ensures maximum reliability

The control and protection equipment featured in the IAIS concept has the following characteristics:

- Distributed signal processing
- Numerical technology
- Deterministic, fiber-optic process bus (100 MHz, as per IEEE 802.12)
- Modular hardware and software
- Software library containing the control- and protection-related functions
- Fully type-tested products

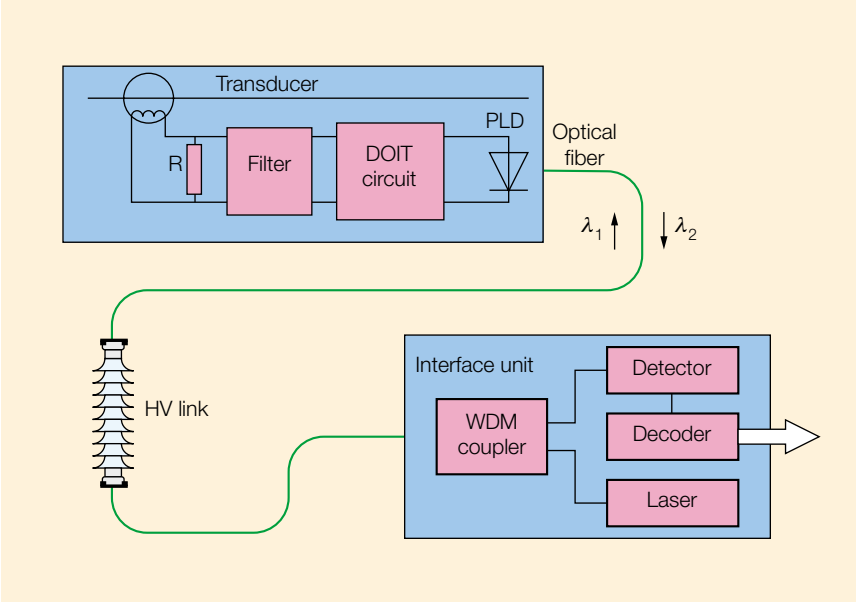
The high level of functional and operational reliability is in large part due to the use of numerical technology. High reliability is also ensured by early detection of faults evolving in the primary equipment. In addition, erroneous switching – eg without definite cause or due to faults outside the monitored zone – is avoided. Further benefits of the numerical technology include:

- Settings based on primary units
- Storage of events and analogue signals, with time data, for later analysis
- Self-monitoring functions in support of the 'Maintenance on Demand' principle
- Simplified spare-parts inventories due to smaller number of modules

The overall reliability is improved by the reduced number of components and connections compared with conventional substations. The components have been made simpler, communicate over a process bus instead of complex cabling, and feature additional self-monitoring functions.

A further advantage is the possibility of different settings, allowing a range of different network configurations. Modern protection equipment with an improved response curve can be more easily adapted to different load and operating conditions. Automatic adaptation is possible, either by remote or local control. Later expansion of the network is relatively unproblematic.

Basic circuit for measurement and signal processing with the DOIT current sensor **11**



Distributed intelligence

The control system works with distributed computers and is designed to achieve the highest possible degree of horizontal and vertical integration. This has produced a system in which distributed units monitor the substation apparatus locally and communicate with the rest of the substation via the process bus.

Fiber-optic process bus

A key element of the IAIS concept is the serial process bus. This consists of standardized components and, by employing fiber optics, is immune to interference due to faults or switching operations in the high-voltage grid. The large number of parallel cables required in the past are replaced by a few single fiber-optic links. Among the information transmitted on the bus are:

- Measured values received from the current and voltage sensors
- Trip signals
- Signals for circuit-breaker control and monitoring
- Information about interlocks and breaker positions
- Information needed for synchronization
- Values calculated from sampled data
- Events and alarm signals
- Settings, programming signals

Control unit for monitoring the operation of power transformers in accordance with the IAIS concept 12

The process bus is deterministic, ie its operation is based on demand priority. Data encoding is simple, and the maximum delay can be calculated and verified even when the bus is operating at full capacity. Analogue measured data values have a sampling frequency of several kHz. As they are time-tagged to an accuracy of a microsecond, summations, differential and product measurements are carried out with no loss of accuracy.

If required, the substation can be equipped with two independent control and protection systems for higher reliability. This fulfils the single fault criterion .

The response time in the event of a fault is equal to or shorter than in conventional substations; in the latter the total response time is the sum of the response times of all the relays in the tripping chain. Communication times on the process bus are much shorter than this. The high-speed bus and the steady-state output units therefore ensure very short system operating times. Collisions and delays are not possible due to the deterministic behaviour of the bus.

Protection and control system components

The protection and control system components employed in the IAIS concept are from the Panorama series of modules from ABB Network Partner. The difference between these modules and conventional products is that the former have no A/D inputs and that the measured data signals are transmitted via the process bus. The I/O plug-in printed-board assemblies are replaced by process bus communication between all units in the system.

Modernization of substations

The IAIS concept has special benefits for upgrade projects. All of the IAIS switchgear is compact and takes up a minimum of space. Distributed computers reduce the cabling for the protection and control equipment to a small number of fiber-optic links. Also, due to the flexibility of the system, either individual switchgear units as well as complete substations can be upgraded, in each case with minimal operational downtime and disturbance.

In the past it has generally been difficult to replace the busbar protection system when modernizing substations. The IAIS concept makes this easier since the complete busbar protection is replaced and the switchbays are renewed in stages. The new busbar protection works with old as well as new current sensors. In the case of older CTs, A/D converters are used to transform the signals during the rebuild phase.

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