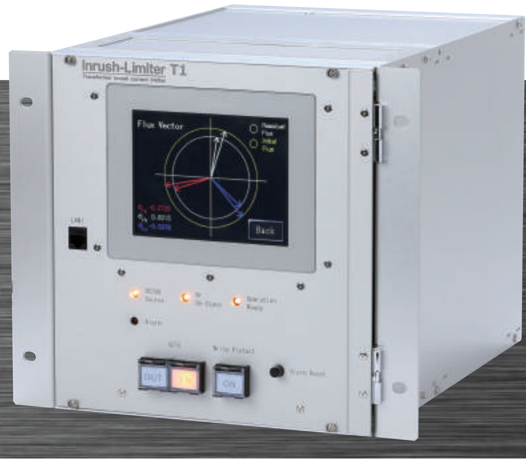
Product catalog

Inrush-Limiter™ T1

Transformer inrush current limiter



KODENSYA CO., LTD.

Kodensya, making progress with our clients through "Technology, Creation, and Challenges"

Inrush-Limiter T1

Transformer inrush current limiter

We, Kodensya, provide advanced control equipment that ensure minimizing transformer inrush current phenomena that would be inevitably caused in important load area whenever transformers are energized by associated breaker closing operation, and by that various electrical and mechanical load obstacles can be effectively dissolved.

We have realized ultimate breaker closing timing control system to minimize inrush current phenomena and to solve the resulted obstacles that have been widely recognized as 'unsolved keen load disturbance problems'.

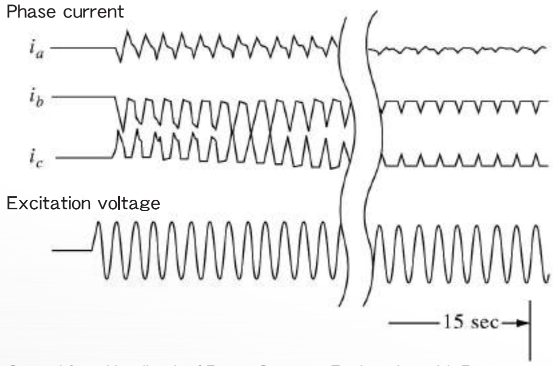
Inrush-Limiter™ T1

Transformer inrush current limiter

Transformer (magnetizing) inrush-current phenomena

Transformer (magnetizing) inrush current phenomena is transient phenomena with aspect of heavy phase-unbalanced and wave form distorted voltage drop and inrush current, which appear inevitably on various loads in the adjacent wide local power system of the associated transformer.
Whenever a transformer in a power system under no-load condition is reenergized by the associated circuit-breaker manual closing operation, the severe transient phenomena would be caused and would continue rather long duration of a few seconds, a few ten seconds or even a few minutes, and so that various obstacles would be caused on motor driving systems, on system control and protection equipment as well as on power electronic circuits for various purposes.
Unsuitable irregular operation of motor driving systems(pulsing operation, rapid emergent overheat of the rotors etc.), of various automatic controlled production systems and of power electronic equipment, undesirable mal-operation of protective relays, and further no-fuse breakers(or fuse) tripping may be typical obstacles caused by the phenomena.

Waveforms of inrush-current Figure 1-1



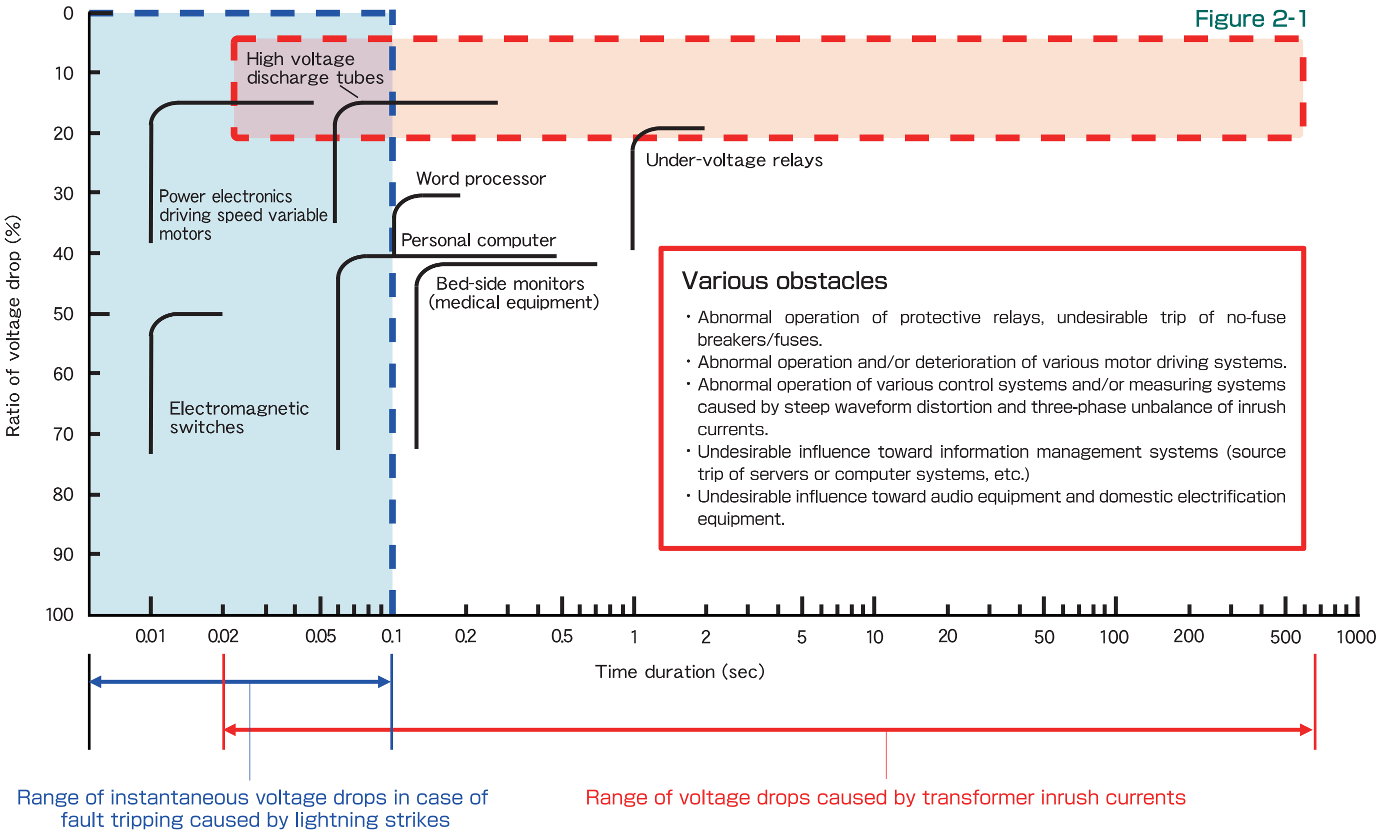
Quoted from Handbook of Power Systems Engineering with Power Electronics Applications, 2nd Edition (Wiley) by Yoshihide Hase

Typical obstacles caused by transformer inrush-current phenomena

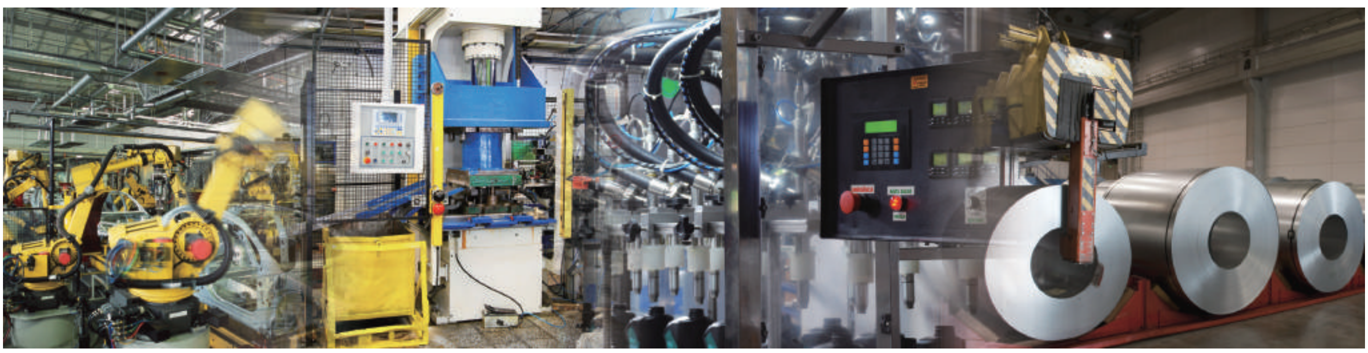
This is transient phenomena typically with appearance of 5 to 20% of phase voltage drops, and further of steep wave form distorted and phase unbalanced currents which would continue rather long duration of over ten seconds.
Fig. 1-1 shows wave form of inrush currents and transformer energized voltage as a typical recorded example. Fig. 2-1 is a graph showing voltage drop(%)versus continuing time duration that would be caused typically by such transient phenomena. As is shown by the figures, the caused system voltage drop would be typically of 5 to 20% and continue 0.5sec to 1minutes,and the three-phase current waveforms would be extremely steep. Furthermore, the characteristics hereunder listed can be commonly recognized.

1 Attenuation time constants are quite long so that the transient phenomena continue long time because these are fundamental frequency transient phenomena with low frequency ripple components.
2 The voltage drop and the current steep waveform distortion would together make double obstacles.
3 The phenomena are caused inevitably every time whenever a transformer is reenergized by the associated breaker closing operation so that they are quite high frequent phenomena.
4 The obstacles may apt to be caused widely in the associated local power network because these are fundamental frequency transient phenomena so that attenuation through travelling would be quite slow.

Figure 2-1



Quotation : a official data issued by Japan Electric Engineer's Association (JEEA)



The photos are for illustrative purposes only.

Inrush-Limiter T1

Transformer inrush current limiter

Transformer inrush current phenomena, the appearing mechanism and the restraining method

Residual fluxes caused in the transformer three phase core whenever it is disconnected by an associated breaker trip is not the core flux values at just the instant time of the breaker tripping.

Figure 3-1

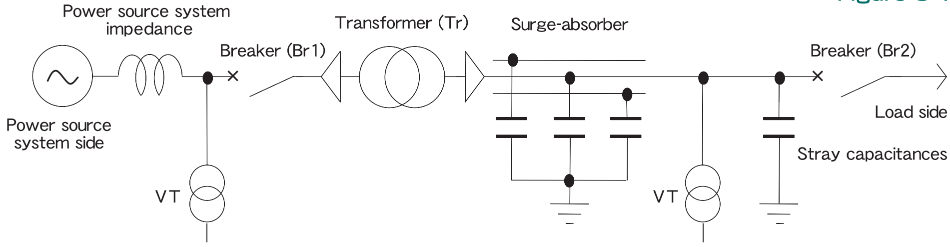


Fig. 3-1 shows a typical connection diagram of a load transformer (Tr) which is connected with the power source network through the HV-side breaker (Br1) and with the load circuit through the LV-side load breaker (Br2). Besides, surge absorber (parallel circuit of capacitors and arresters), VT as well as stray capacitance of the lead conductors (lead wires or power cables) generally exist between the transformer and the LV-side breaker as so called minute load, so that the closed loop circuit consisted with such minute load and the transformer LV-side coil still exists.

Then, whenever the transformer under no-load condition with LV-side breaker (Br2) disconnected mode is manually tripped by HV-side breaker (Br1), transient phenomena of voltages/currents/fluxes appear in the LV-loop circuit and continue a certain duration.

Furthermore, the transient phenomena can be considered as three-phase balanced phenomena because of the reason a) and b) hereunder described.

a) All the circuit of HV-/LV-side and of the transformer are with three-phase balanced condition through the time interval of just before and after the transformer manual disconnecting operation by the HV-side breaker trip.

b) The tripping timings of the HV-side breaker's three phase poles are exactly simultaneous and the timing difference of each pole tripping would not appear, because the breaker can break small excitation current of the transformer(usually 1A or less) simultaneously just at the timing of breaker's mechanical opening by current chopping mode(while in case of fault current or load current tripping, the electrical tripping timings of three poles are different because current zero timing are different in each phase .).

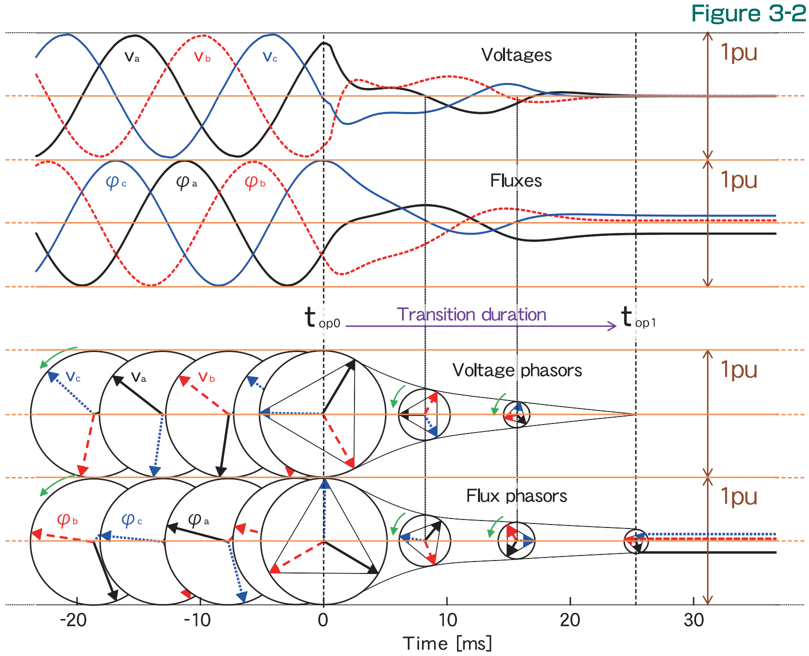
Therefore the transient phenomena of voltages, currents and fluxes are of three-phase balanced, and the transient time interval are common for the three variables. In other words, the three-phase voltages and currents transient phenomena are initiated at the HV-side breaker trip timing t_{op0} and they disappear simultaneously at the transient end-timing t_{op1}, while the transient phenomena of three-phase core fluxes are also initiated at t_{op0} and the flux values would be converged to three-phase balanced certain values (in name of residual flux values) at the same timing t_{op1}.

In conclusion, the true values of the residual fluxes reserved in the core must be the three-phase flux values at the cease timing t_{op1} of the transient phenomena, instead of the timing t_{op0}, and the phasor of the residual fluxes would preserve the form of three-phase balanced equilateral triangle, while the magnitude of the flux phasor at the timing t_{op1} may be shrunken in comparison with that at the timing t_{op0}.

a. Physical aspect of transformer residual fluxes (Theoretical background of our products)

Waveforms of voltages and fluxes, and the phasors expression in the duration of the transient phenomena just after transformer shut-down.

Figure 3-2



The Fig. 3-2 shows one of field test data measured at a 66kv substation that shows transient phenomenon just before and after the timing of HV-side breaker tripping. In the figure the upper side wave forms show three-phase voltages v_a, v_b, v_c recorded from the LV-side VT, and the lower side waveforms show fluxes values of three-phase cores φ_a, φ_b, φ_c that were generated by integral calculation of the above voltages until the timing t_{op1} utilizing the recorded digital sampling data in our equipment.

The both wave forms of the voltages and fluxes are obviously three-phase balanced modes through all the interval, so that the three-phase voltages and the fluxes can be expressed as the phasors with equilateral triangular forms that rotate as are shown in the lower part of the Figure.

In the transient interval between the time t_{op0} and t_{op1} (θ_{op0} and θ_{op1} by radian notation), the voltage phasors attenuate while rotating with the free angular velocity and finally disappear at the timing at t_{op1}. The flux phasors also attenuate while rotating and the rotating speed become gradually slow and finally stop at t_{op1} because the fluxes can be drawn as the time-integration of the voltages. Of course, the three-phase balanced fluxes values at this moment $\varphi_a(t_{op1})$, $\varphi_b(t_{op1})$, $\varphi_c(t_{op1})$ (or $\varphi_a(\theta_{op1})$, $\varphi_b(\theta_{op1})$, $\varphi_c(\theta_{op1})$ by radian notation) correspond to the real residual fluxes φ_a, φ_b, φ_c.

b. Control Algorithm to restrain transformer Inrush current phenomena (Kodensya's patent method)

True residual fluxes φ_a, φ_b, φ_c of a disenergized transformer preserve three-phase balanced condition that can be expressed as a set of equilateral triangle phasors as was already explained.

In next, when the transformer is again energized at time t_{cl}(or θ_{cl} by radian notation) by the associated HV-side breaker closing operation, the initial energized fluxes appear in the transformer three-phase cores that are also three-phase balanced and can be expressed as another set of equilateral triangle phasors $\varphi_a(t_{cl})$, $\varphi_b(t_{cl})$, $\varphi_c(t_{cl})$ (or $\varphi_a(\theta_{cl})$, $\varphi_b(\theta_{cl})$, $\varphi_c(\theta_{cl})$ by radian notation).

So, the instantaneous flux values of the each cores become the superposed values of the residual fluxes $\varphi_a(\theta_{op1})$, $\varphi_b(\theta_{op1})$, $\varphi_c(\theta_{op1})$, and the initial energized fluxes $\varphi_a(\theta_{cl})$, $\varphi_b(\theta_{cl})$, $\varphi_c(\theta_{cl})$. Therefore, if the scalar value differences $\Delta\Phi_a$, $\Delta\Phi_b$, $\Delta\Phi_c$, of both sets of the phasors exceed the designed core flux saturation level in any phase, severe inrush current phenomena would be inevitably caused. In contrast, if reasonable timing control of the HV-side breaker closing operation is conducted in order to minimize the fluxes differences $\Delta\Phi_a$, $\Delta\Phi_b$, $\Delta\Phi_c$, inrush current phenomena can be effectively restrained.

Fig. 4-1 shows test data conducted in the mimic transmission system in our research laboratory in that large number of model transformer tripping and closing operations were recorded. The data clearly explain that inrush current would become minimum if the breaker closing timing θ_{cl} is controlled to become in phase with θ_{op1}, (in stead of θ_{op0}), and in contrast it would become maximum if the breaker closing-timing θ_{cl} is controlled to become inverse phase with θ_{op1}.

Fig. 4-2 shows the bird's-eye view of the data of the recorded inrush current values by the parameters θ_{op1} and θ_{cl}.

Plotted graph of test results using the mimic transmission line model system

Figure 4-1

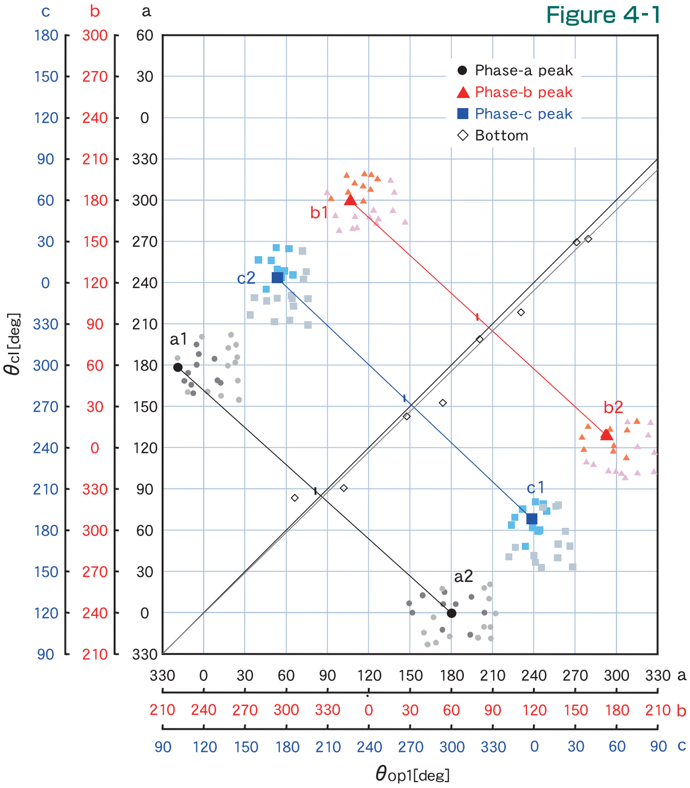
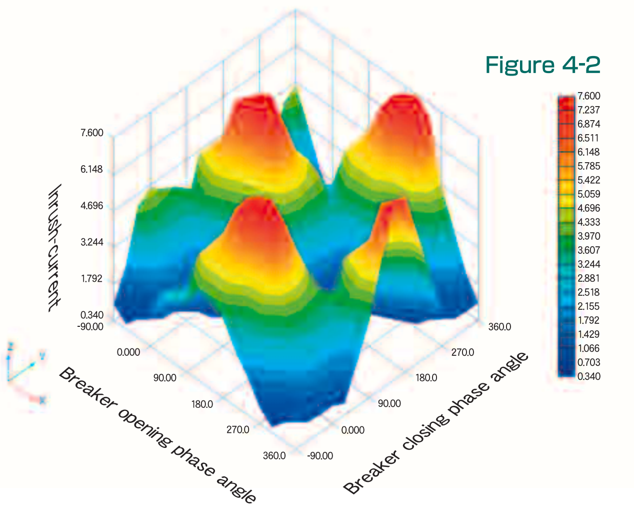


Figure 4-2



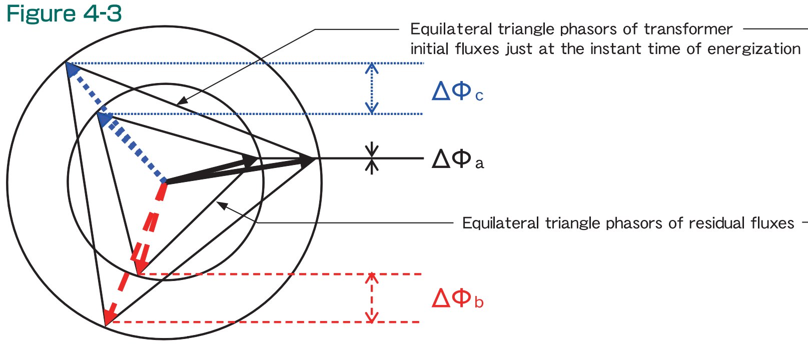
Based on the above described our theoretical backgrounds and the experimental test result, our Transformer Inrush-Limiter T1 series, is equipped with the function to calculate true residual flux values as the terminated values at the timing of the transient phenomena caused after transformer manual tripping and with the function to control the breaker closing so that the phase angles of the set of the true residual flux phasors and that of initial energized flux phasors almost coincide for each other.

The Fig. 4-3 and Fig. 4-4 explain the adopted algorism concept where the phase angular timing of the initial energized flux phasors equilateral triangle is adequately controlled to almost meet the phase angular timing of the true residual flux phasors equilateral triangle while the latter may have been somewhat shrunken because of fluxes attenuation by thermal loss in the cores.

(Patent Number 5343118, Japan)

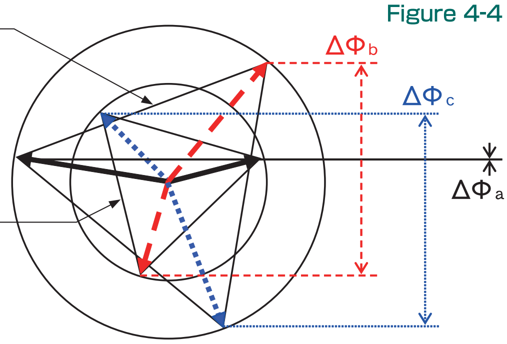
Optimum phase angle closing control [The Inrush-Limiter's algorithm]
(Scalar coincidence control of the minimum residual magnetic flux phase)

Figure 4-3



Inverse phase angle closing control
(This case will be the inrush current at maximum level)

Figure 4-4



Inrush-Limiter T1

Transformer inrush current limiter

Restraining Control Effect of the Inrush-Limiter

We, Kodensya conducted experimental clarification test of our Inrush-Limiter in combination with our mimic transmission line system and the premium performance of the Inrush-Limiter was completely proved through the test. Fig. 5-1and Fig. 5-2 shows wave forms of the recorded three phase inrush currents in typical two different cases.

[Inrush-current Limiter out of service condition]

Fig. 5-1shows a case in that the Inrush-Limiter was out of service, and the transformer was reenergized by the associated breaker closing operation at the timing when the phase angle of initial energized flux phasors become the opposite phase angle 180° in comparison with that of the residual fluxes, and the maximum level inrush current was recorded.

Figure 5-1

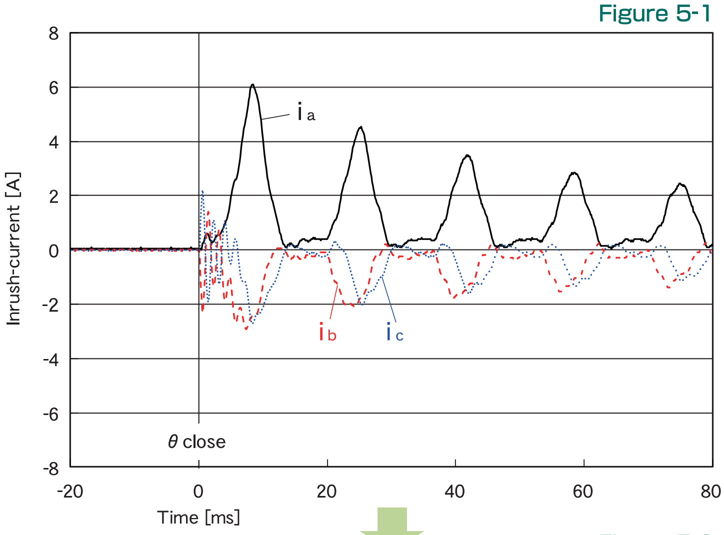
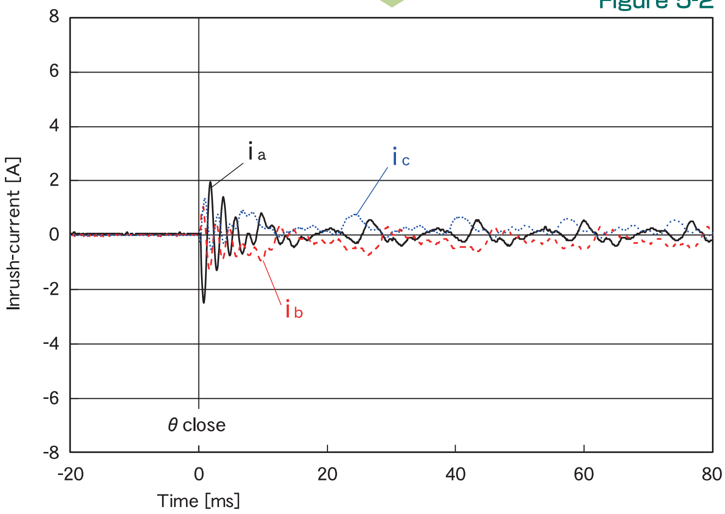


Figure 5-2



[Inrush-current Limiter in service condition]

Fig.5-2 shows the case in that the Inrush-Limiter was in service, and the transformer was reenergized by the associated breaker closing operation at the timing when the phase angle of initial energized flux phasors become in-phase angle in comparison with that of the residual fluxes, and inrush current was not actually caused.

The correlation of the breaker closing angular timing and the caused voltage drops

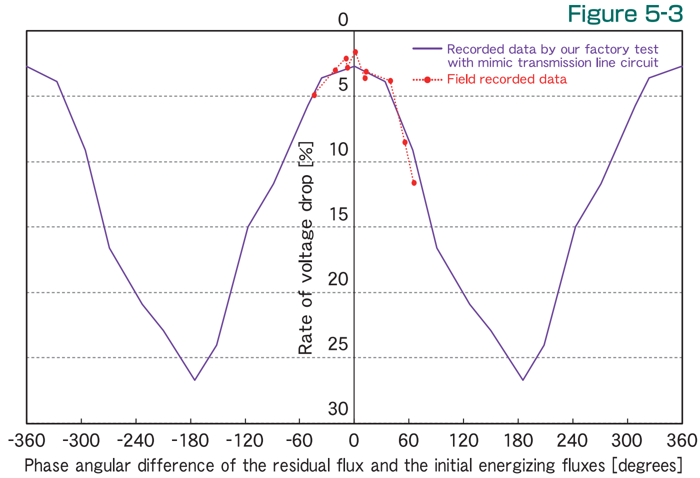
Fig.5-3 shows the summarized correlation between the measured phase angular difference of the residual fluxes and the initial energizing fluxes versus the recorded voltage drops that were obtained in our repeated trial test of the transformer tripping/closing operation using a mimic transmission line model system in our factory.

The horizontal axis shows the measured phase angular difference ($\Delta\theta = \theta_{op1} - \theta_{cl}$) of the residual flux and the initial energizing fluxes, and the horizontal axis shows the recorded voltage drops in %.

If the transformer energization timing is controlled by the Inrush-Limiter, the initial phase angle of the initial energizing fluxes can be controlled to meet that of the residual fluxes within the 0 to 20 degrees, so that the Inrush current and the associated voltage drops can be ideally minimized. The figure curve clearly shows the premium function of the Inrush-Limiter.

By the way the red plotted dots in the Figure 5-3 show actual recorded values by a field test conducted at a large graphite furnace factory, and the premium performance of the equipment was again proved.

Figure 5-3



$\Delta\theta = \theta_{op1} - \theta_{cl}$

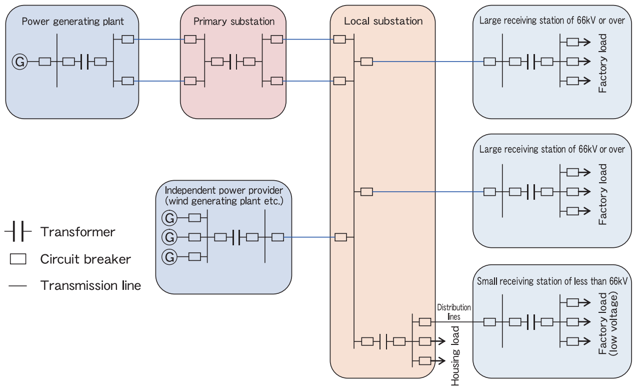
Application of the Inrush-Limiter

Substations for that the Inrush-Limiter can be available.

The Inrush-Limiter is available for any voltage class substations such as 66-500kV class high voltage substations and 3-33kV class substations for distribution systems or for load factories. In other words, they can be adopted for any substation or power receiving station owned by power utilities, public authorities and private owners and by small distribution power providers , that may include typical loads such as public facility-load (rail-load, water/gas supply system, building loads etc.), factory-load , small power generating plants as well as ordinal housing loads.

The Inrush-Limiter is applicable to all transformers as shown on Fig. 6-1.

Figure 6-1



Interface

Input and output inter face requested by the equipment are listed hereunder :

Input :

・Three-phase voltages of the power source side as of the secondary voltages of the associated voltage-transformer VT1.

・Three-phase voltages of the load side as of the secondary voltages of the associated voltage-transformer VT3 or VT2.

・The primary side breaker' on-off switching contacts (pallet switches).

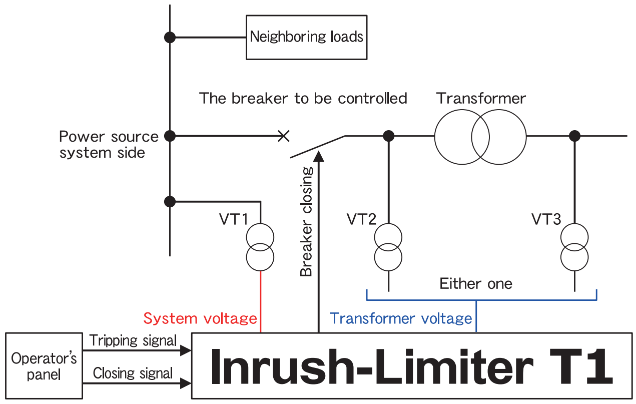
・Tripping / Closing signals from the operator's panel.

Output :

・The breaker tripping/closing signals and the alarm signal.

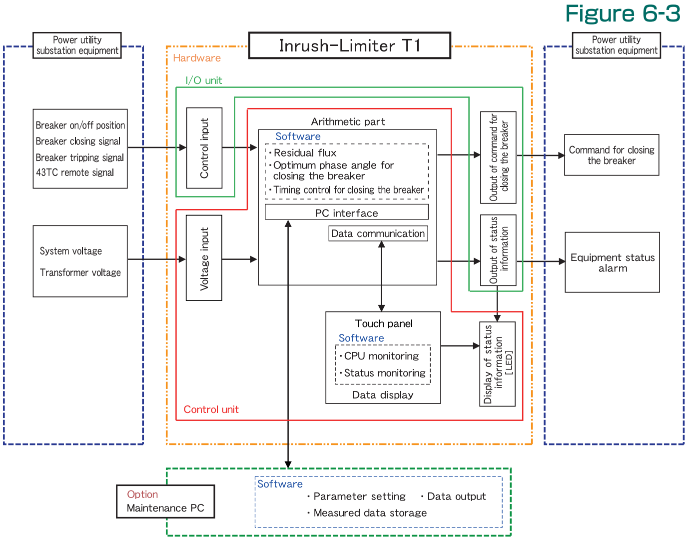
The equipment can be adopted for the transformers of any MVA-capacity, kV voltage and of the winding connection.

Connection Diagram　　Figure 6-2



System Configuration

Figure 6-3



Function

Functions of the unit are shown below.　　Table 6-1

Item	Function
Voltage input	The secondary voltage of the VT for the system voltage (primary side of the circuit breaker for the primary side of the transformer) and transformer voltage (primary or secondary side of the transformer) is input to the control unit via an input converter.
Control input	Receives an external control signal and inputs it into the control unit.
Output of command for closing the circuit breaker	Receives a command for closing the circuit breaker from the control unit and outputs it to the external device (circuit breaker).
Output of status information	Outputs information about unit status and alarms to external devices.
Display of status information	Displays information about unit status and alarms.
Touch panel	Displays information about operation history of a circuit breaker and alarm monitoring.
Arithmetic part	Performs arithmetic operation and control. It consists of a power unit, CPU unit, DI/O unit and A/D unit.
Maintenance PC	It provides a LAN connection to a PC intended for adjusting the interface with the controller and maintenance work.

Note : Refer the Fig. 8-1 for the interface details between the Inrush-Limiter and the substation control board

Inrush-Limiter T1

Transformer inrush current limiter

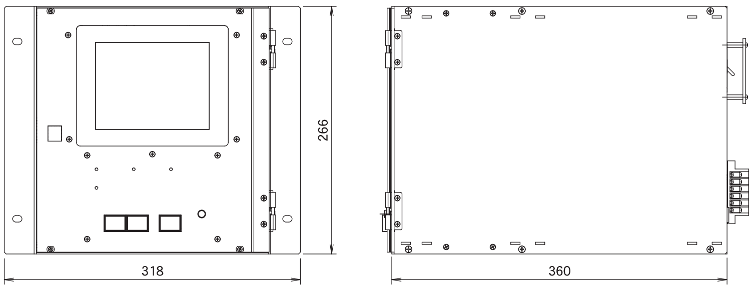
Specifications and Dimensions

The structure

The Inrush-Limiter is composed with the two unit boxes that are the Control unit and the I/O unit.

Control unit

Figure 7-1



Frontward　　Right side

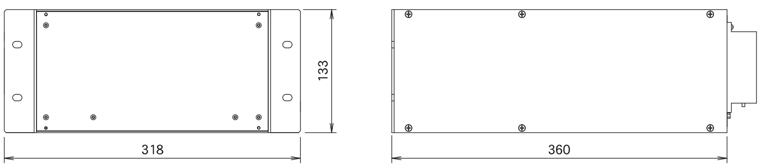
■ The front panel of the control unit is arranged with the operating and signal indicating devices listed hereunder:

- touch panel for data input and display
- LED lamp for the state and alarm indication
- selection switch (on/off selection of the equipment)
- writing lock switch
- alarm reset switch

■ The connection terminal connectors and 24Vdc-control voltage switch are arranged at the backward panel of this unit.

I/O unit

Figure 7-2



Frontward　　Right side

■ The I/O unit is equipped with input / output relays and voltage conversion devices. Also the input/ output terminals including source connectors and dc-control voltage switch are arranged on the backward panel.

Specification of the Unit

Specifications of the unit are shown below.

Table 7-1

Item \ Description	Control unit	I/O unit
Part no.	T1-2□□	IL-IO-DC110V/DC125V
Mounting method	Rack or panel mount	
Outer dimension W×H×D[mm]	318 × 266 × 360 (not including projections such as terminal blocks)	318 × 133 × 360 (not including projections such as terminal blocks)
Surface treatment	Silver colored anodized aluminum	
Weight [kg]	9	7
Power supply	Power supply from the I/O unit (24VDC)	110VDC(90-120V), 200W or 125VDC(100-135V), 200W (For other power supply voltage, please contact us.)
CPU	CPU : Atom E3845 1.91GHz Calendar backup battery life : 10 years	—
Sampling rate	7,200Hz for 60Hz circuit 6,000Hz for 50Hz circuit	—
Touch panel	5.7inch(QVGA) Display colors : 65,536 Backlight service life : 50,000 hours or more Touch panel service life : 1 million times or more	—
Communications	Ethernet 100Base-T or above for communication with a maintenance PC. (Other communication function requests, please contact us.)	—
Cooling method	Natural cooling	
Ambient temperature and humidity	−20℃ to 60℃(no freezing permissible) and 20% to 90%RH(no condensation permissible)	
Environment	No harmful smokes or gases, salty gases, explosive gases, water drops or vapor, excessive dust or powder, excessive vibration or impact, or heat convection obstructions are permissible.	
Withstand voltage*	2000VAC, 1 minute (Collective grounding of input terminals) ＊Except 24VDC circuits	

Connection diagram

The Fig. 8-1 shows the connection diagram of the Inrush-Limiter with the station facilities.

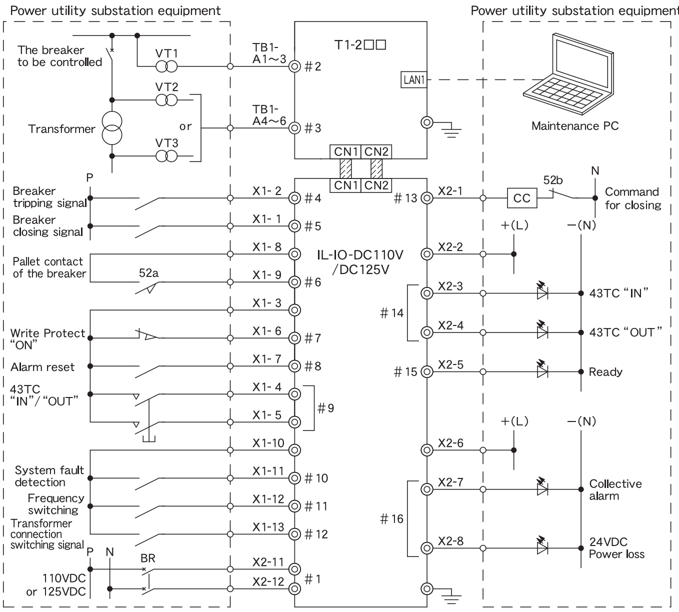


Figure 8-1

The connection between the Inrush-Limiter and the station facilities:

To be connected by control cables.

The connection between the two unit boxes:

To be connected by an attached connecting cable.

The connection between the Inrush-Limiter and the PC (Personal computer) for maintenance use:

To be connected through the attached LAN-cable. The application software for maintenance will be supplied.

Input/Output Signals

The following table describes the input and output signals.

Table 8-1

#	Signal name	Type	Description	Specifications
1	Control power	Power	Input the control power of 110/125VDC for this unit.	110VDC(90-120V), 200W or 125VDC(100-135V), 200W
2	System voltage	Analog input	Breaker primary side VT three phase voltages to be supplied. 3-phase line voltage 110V, 50/60Hz	VT load 0.1VA or less.
3	Transformer voltage		Breaker secondary side VT voltages (transformer HV-side or LV-side VT voltages) to be supplied. 3-phase line voltage 110V, 50/60Hz	
4	Trip signal	Digital input	Add a current relay to the final stage trip coil of the circuit breaker and connect the relay to this unit. Input the 1a signal or the circuit breaker pallet contact.	No-voltage contacts (1a). Contact input rating : 110/125VDC, 20mA or more.
5	Close signal		Signal for final stage operation of closing the circuit breaker.	
6	The palette contacts of the associated breaker		Auxiliary contacts of the breaker to be supplied.	
7	Write Protect "ON"		Circuit breaker primary side auxiliary contact.	No-voltage contacts (1b). Contact input rating : 110/125VDC, 20mA or more.
8	Alarm reset		Momentary-switch contact for resetting operation.	No-voltage contacts (1a). Contact input rating : 110/125 VDC, 20mA or more.
9	Device enable / disable switch		Momentary-switch contact for the enabling/disabling operation. Use it when remote operation is required.	No-voltage contacts (2a, or 1a+1b). Contact input rating : 110/125VDC, 20mA or more.
10	System fault detection		To detect a system fault, a separate relay available for this purpose is required. For further details please contact us.	No-voltage contacts (1a). Contact input rating : 110/125VDC, 20mA or more.
11	Frequency switching (optional)		Switching the power frequency between 50 and 60 Hz. For further details please contact us.	
12	Transformer connection switching (optional)		Switching between Y and Δ connections for the transformer. For further details please contact us.	
13	Command for closing	Digital output	Outputs the command for closing the circuit breaker.	Transistor output Switching capacity 110/125VDC, max. 7A
14	Device enable / disable status		Outputs the enabled / disabled state of the device, it can be used for display purpose. Use it when remote display is required.	Relay output Contact capacity 125VDC, max. 0.3A 110VAC, max. 2A
15	Ready		Contact is closed with "Ready" on.	
16	Alarm		Contact is closed with the device fault detected.	

Inrush-Limiter T1

Transformer inrush current limiter

Installation Procedures

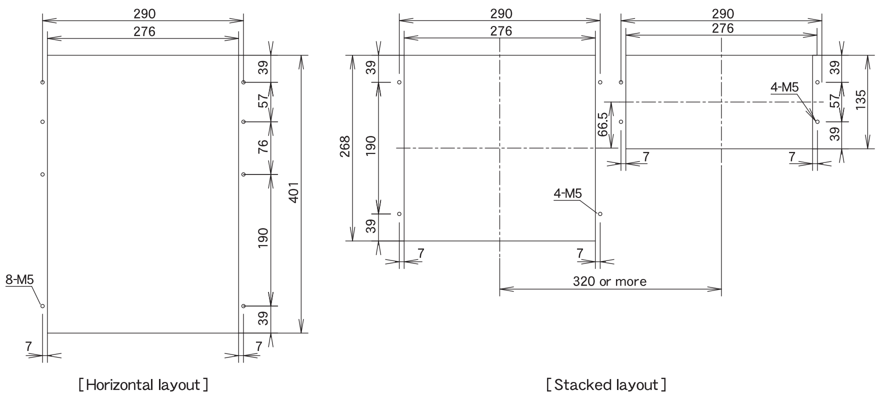
Construction and Installation

The Inrush-Limiter is designed as a modular unit that is easy to install or remove in a control panel. It can be installed in the substation control panel, or in a stand alone cabinet.

- For installation, panel cut as shown on the right, fix the each unit with 4-M5 screws.
- Unit arrangement,
  In the case of portrait arrangement :
  The input / output unit is above
  In case of sideways :
  The input / output is on the right
  It is standard to arrange as described above.
- When installing multiple sets please refer to the placement of the free-standing chassis below. For unit indirect connection, please specify the cable length according to the arrangement dimension.

Panel cutout dimension

Figure 9-1



Panel building models

Table 9-1

Type	for Four banks	for Two banks	Front door panel	Custom made structure
Part number	IL-EC04-□	IL-EC02-□	IL-EC01-1	IL-ECX-□
Overview images				Note : Custom made structure can be supplied upon by client's request.
Specification	●for Four banks in maximum ●700(W)×2,300(H)×450(D)[mm] (excluding the size for the name plate and channel base)	●for Two banks in maximum ●350(W)×2,300(H)×450(D)[mm] (excluding the size for the name plate and channel base)	●for single bank with front door ●700(W)×2,000(H)×600(D)[mm] (excluding the size for the name plate and channel base)	

HMI

HMI (Human Machine Interface) application software is available.

Liquid crystal panel indicator

- The calculated recent residual fluxes
- Target timing of appropriate breaker closing
- Latest breaker operation histogram

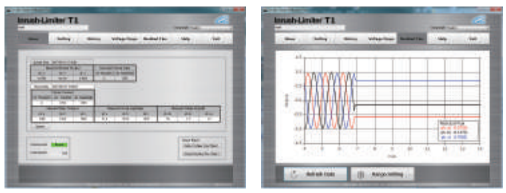
Figure 9-2

Software tool

Application software is available by that appropriate operation and maintenance works can be done on a PC (Personal computer).

Figure 9-3

- Setting of necessary parameters
- Graphical display of recorded voltage drop values
- Reporting histogram recording
- Manual control operation of the equipment



Safety Precautions	Instruction manuals for clients are available for appropriate application.

◆Specifications are subject to be replaced without notice for ongoing product modifications and improvements.

KODENSYA CO., LTD. http://inrush-limiter.jp E-mail:info@kodensya.co.jp

Head Office	: 222-1 Hamamachi, Nobeoka-shi, Miyazaki 882-0862, Japan	Phone : +81-(0)982-33-3602	Fax : +81-(0)982-33-3684
Miyazki Branch	: 2940-63 Aza-shimonoyama, Shimonaka, Sadowaracho, Miyazaki-shi, Miyazaki 880-0212, Japan	Phone : +81-(0)985-62-7272	Fax : +81-(0)985-62-7273
Nichinan Office	: 1120-19 Ooaza-hirano, Nichinan-shi, Miyazaki 887-0015, Japan	Phone : +81-(0)987-24-0326	Fax : +81-(0)987-24-0609
Oita Office	: 6-25 Kubarukita, Oita-shi, Oita 870-0324, Japan	Phone : +81-(0)97-593-5012	Fax : +81-(0)97-593-5026
Tokyo Sales Office	: Room#207b, Miyazaki-ken Tokyo bldg., 4-8-2 Kudan Minami, Chiyoda-ku, Tokyo 102-0074, Japan	Phone : +81-(0)3-6272-9913	Fax : +81-(0)3-6272-9914
Fukuoka Sales Office	: Office Parea Isoda Ⅱ-B-1, 2-10-28 Isoda, Hakata-ku, Fukuoka-shi, Fukuoka 812-0881, Japan	Phone : +81-(0)92-588-7080	Fax : +81-(0)92-588-7082

PA004-1809