Understanding the Impact of Autoreclosing on Voltage Ride-Through of Large Electronic Loads

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***Abstract*—Large electronic loads (LELs), such as artificial intelligence (AI) data centers, exhibit voltage-sensitive behavior, rapidly transferring to backup power supply systems within a few cycles. Autoreclosing, a standard practice for fault clearing in high-voltage transmission lines, can trigger this transfer. This study goes through current autoreclosing practices on high-voltage transmission lines and incorporates an autoreclosing model to show their impacts on voltage-sensitive LELs. Results show that even brief reclosing interruptions, under extended dead time during high-speed reclosing, can reduce bus voltage below UPS ride-through thresholds and cause unnecessary LEL disconnection. The findings emphasize the need for coordination between reclosing control and UPS ride-through requirements to prevent simultaneous tripping of large data center loads during temporary transmission faults.**

***Index Terms*—Uninterruptible Power Supply, Artificial Intelligence, Data Center, Autoreclosing, Protection**

I. Introduction

Artificial intelligence (AI) data center demand is surging, with some projections suggesting that global data center demand could more than triple by 2030 [1]. Given that large electronic loads (LELs) can require up to 500 MW per facility, their expansion exacerbates power quality challenges. Double-conversion uninterruptible power supply (UPS) devices are commonly used in AI data center power architectures. This device is designed to provide conditioning and stabilization of the income supply and transfer to backup power during disturbances [2].

NERC has reported growing reliability concerns as large data centers exhibit voltage-sensitive behavior, rapidly transferring to UPS backup systems during grid disturbances and causing abrupt load changes [3]. Such events can exacerbate voltage and frequency instability, particularly in cases of overvoltage conditions. Discussions with data center operators during the NERC incident review further revealed that their UPS control logic relies on disturbance counting. This tracks the number of disturbances within a preset time window and transfers to backup supply once a threshold is reached.

Due to this, transmission operators such as ERCOT have recognized the need to define standardized voltage ride-through (VRT) curves for UPS devices in LELs. ERCOT has proposed a draft VRT curve, but it remains non-binding and under evaluation [4]. However, the practice of automatic reclosing, also known as autoreclosing, could increase the risk of LEL tripping. Utilities commonly use this practice to clear temporary faults on transmission and distribution lines, which are the most common. This is done to quickly re-energize the line, restore system integrity, or service to customers, all of which can be achieved much more rapidly than by manual control [5].

The objective of this paper is to address the issue of unnecessary tripping in voltage-sensitive LELs. Section II presents the fundamental concepts of autoreclosing practices in transmission systems and explains key parameters, including the number of reclosing attempts, dead time, and supervision. Section III describes the developed autoreclosing model and the logic for the reclose sequence. Section IV discusses the implementation of the ERCOT-proposed UPS VRT curve and analyzes two simulation cases to assess the impact of high-speed reclosing on UPS VRT performance.

II. Autoreclosing in Transmission Systems

The autoreclosing process discussed in this section is described in accordance with IEEE Std C37.104-2022 [5]. It explains the number of reclosing attempts, duration of the dead time, reset time, lockout, and supervision. Additionally, possible impacts on LELs are discussed for each, where applicable.

A. Number of Reclosing Attempts

Based on the number of autoreclosing operations programmed in the relay, a scheme may be configured as single-shot autoreclosing, in which the circuit breaker recloses once within a prescribed interval. This reclose attempt may be performed either high-speed or time-delayed, depending on system requirements. When more than one reclose attempt is permitted during a single disturbance event, the scheme is classified as a multiple-shot autoreclosing scheme.

The frequency of disturbance events within a predefined time window can influence the tripping of LELs, as reported in [3], where approximately 1,260 MW of load was lost due to this issue. The incident review noted that the data center operator's UPS control logic was configured to transfer to backup supply once a threshold number of disturbances occurred within a set period; after the sixth consecutive event, the system initiated a transfer, disconnecting the entire load. In this context, multi-shot autoreclosing can unintentionally produce exactly this sequence of disturbances. Each reclose attempt into a temporary or permanent fault generates an additional

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TABLE I
MINIMUM DEIONIZING FOR DIFFERENT SYSTEM VOLTAGES

System voltage (kV)	Minimum dead time (cycles)
69	13
115	14
138	15
161	16
230	18

voltage sag, and a series of such shots may accumulate to the disturbance threshold used by the UPS control logic, triggering an unnecessary transfer despite the fault being temporary.

B. Dead Time

The dead time, also referred to as the reclose interval, is the period during which the interrupting device remains open and the controlled circuit is de-energized following the tripping operation for a fault and before the autoreclosing attempt [5]. Several factors must be considered when selecting an appropriate dead time. A key consideration is the ionized-gas path created by the fault arc. If sufficient time does not pass for the gas to disperse, the arc will start conducting again after reclosure. The required de-ionization time depends on factors such as system voltage, conductor spacing, fault-current magnitude, and prevailing weather conditions [6]. An example of a minimum de-ionization delay is provided by (1), which estimates the time required for de-ionization in cycles [7]. The calculated minimum de-ionization times for different voltage levels are summarized in Table I.

$$t = 10.5 + \frac{V_{L-L}}{34.5} \quad (1)$$

Some utilities use single-pole switching (SPS) for single phase-to-ground (SLG) faults, since most faults are of this nature. By tripping and reclosing only the faulted phase, synchronizing power continues to flow through the healthy phases, reducing angular separation between interconnected systems and minimizing system disturbance during the dead time [6]. SPS requires phase-selective tripping and independent pole mechanisms, and modern numerical relays provide this logic. A key drawback is that the de-ionization time is longer for single-phase faults due to capacitive coupling between the faulty and healthy phases, which necessitates a longer dead time compared to three-phase autoreclosing [8].

The dead time could affect the tripping of LELs, especially during high-speed switching operations. If the proposed UPS VRT curve is considered and the high-speed operation lies between 0.5 and 2 seconds, the first autoreclose shot may occur while the temporary fault is still present. This can violate the VRT capability curve and cause the LEL to trip due to the disturbance. This is further illustrated in Section IV through a simulation case.

C. Reset Time and Lockout

The reset timer returns the relay to a ready condition once the breaker has reclosed successfully. After a successful shot, the timer expires and the autoreclosing logic fully restores itself, allowing the relay to respond to any future fault. The choice of reset time typically reflects utility practice and the expected duration of fault clearing [5].

If the reclose attempt is unsuccessful, as would occur during a permanent fault, the reclosing relay transitions into a lockout state, preventing any further automatic closure of the breaker. The relay enters lockout only after all programmed reclose attempts have been used without success. The lockout is cleared only after the breaker is closed manually, either locally or through remote control, and the breaker must remain closed for a specified interval to allow the relay to confirm that the system is stable and no fault persists [5], [7].

D. Autoreclosing Supervision

The following supervision methods are described in accordance with IEEE Std C37.104–2022 [5]. Autoreclose supervision is used to prevent autoreclosing that may cause damage to equipment, minimize the number of unsuccessful autoreclosing attempts, and help maintain system stability.

1) Voltage Supervision: Ensures that the appropriate voltage conditions are present across the breaker before an autoreclose attempt. Typical schemes include dead-line/dead-bus (DLDB), live-bus/dead-line (LBDL), live-bus/live-line (LBLL), and live-line/dead-bus (LLDB).

In most applications, supervision is used for LBDL or LBLL conditions. In a leader–follower reclosing scheme, the leader terminal recloses onto a dead line (i.e., one with zero or very low voltage). In contrast, the follower terminal recloses only after normal voltage has been restored, when the line is re-energized. For lines with tapped loads capable of back-feeding, dead-line sensing ensures the line is sufficiently de-energized before re-energization.

Typical settings are designed to distinguish between normal energized conditions and residual or induced voltages. LBLL detectors are often applied near 0.8 p.u., while dead-line supervision is usually set low, around 0.2–0.3 p.u., to confirm the line is truly de-energized.

2) Synchronism Check Supervision: This is applied when there is a possibility of excessive phase angle, frequency slip, or voltage magnitude difference across the breaker contacts prior to reclosing. This could adversely affect the system, generators, or customer equipment. The synchronism-check element monitors these differences and ensures that the breaker closes only when they are within acceptable limits. If studies or operating experience indicate that a line is prone to separation or out-of-step conditions, synchronism-check supervision may be added even when it is not normally required, since preventing undesired LBLL reclosing under these conditions helps avoid equipment damage.

3) High-Speed Reclosing Supervision: For high-speed autoreclosing (typically under 1 s), utilities often choose not to apply synchronism-check supervision because the reclosing interval is short enough that the synchronizing angle changes very little during the dead time. Nonetheless, some utilities still apply a degree of supervision even during high-speed

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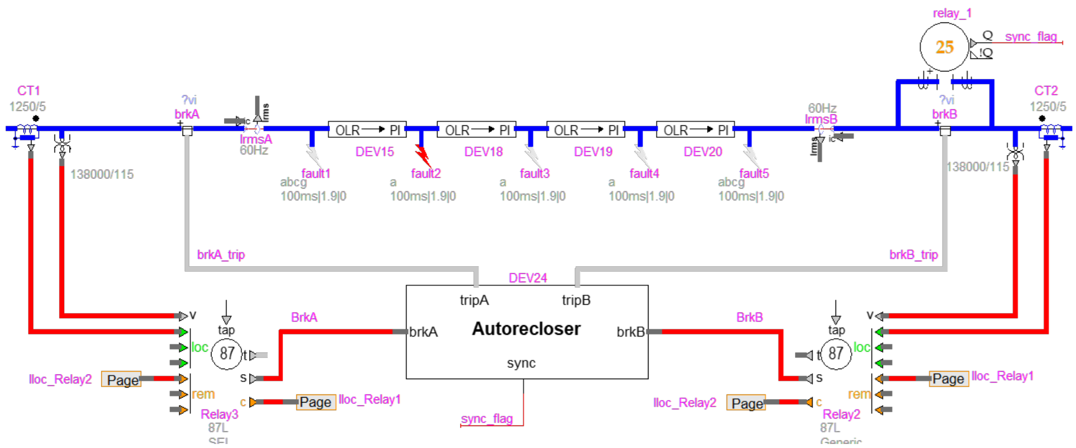

Fig. 1. Autoreclosing model with breaker logic and supervision.

operation. One common approach is for the lead terminal to autoreclose without supervision, while the follower terminal recloses only after normal voltage has been restored on all three phases. The reclosing relay timing is initiated by tripping, hence the difference in closing time between the two ends is minimal.

III. Autoreclosing Model

The proposed autoreclosing model reproduces the control logic of circuit breaker tripping and reclosing during transmission line faults. Both circuit breakers trip upon detection of a fault, initiated by the pilot differential protection scheme. After an intentional dead time, only one terminal, designated as the leader, attempts the first high-speed reclosing shot, while the follower terminal remains open under supervision.

A. Model Description

To simulate the autoreclosing sequence, an autoreclosing model is developed that receives input from protection relays regarding the type of fault, illustrated in Fig. 1. The leader terminal is represented by Breaker A, and the follower by Breaker B. Each breaker is equipped with current and voltage transformers (CTs and VTs) rated 1250 A / 5 A and 138 kV / 115 V, respectively. The 138 kV 100-mile transmission line is divided into four equal segments to allow fault placement along its length and evaluation of relay coordination. The pilot differential protection scheme provides simultaneous tripping signals to both breakers; the one receiving the trip signal first initiates line isolation.

B. Autoreclosing Sequence

A leader–follower autoreclosing scheme with two reclose attempts is applied on the 100-mile, 138-kV transmission line. The sequence of events is illustrated in Fig. 2. A single-line-to-ground fault occurs at 0.1 s, approximately 25 miles from terminal A. Fault detection at both terminals initiates a trip, and the breakers open in four cycles, which includes both detection time and breaker operating delay, reaching a total of 0.167 seconds.

The first autoreclose attempt at terminal A is a high-speed shot intended to clear temporary faults. Based on the minimum arc de-ionization interval for a 138-kV line, a 15-cycle (i.e., 0.25 s) dead time is applied. Breaker A recloses at 0.417 s, but the fault remains, and the breaker re-trips following another four-cycle delay. Terminal B remains open throughout this interval, consistent with a leader–follower approach.

Following the unsuccessful high-speed attempt, terminal A enters its delayed dead time of 5 s. Breaker A performs its second reclose at 5.484 s, by which time the fault has cleared and the breaker remains closed. Had the fault persisted, this second failure would have driven the scheme to lockout.

Once terminal A successfully re-energizes the line, terminal B initiates its follower sequence. A one-second supervision delay, combined with synchronism check verification, is applied to ensure stable system conditions before reclosing. With acceptable synchronism, breaker B closes at 6.484 s, restoring the line to normal service. If synchronism is not achieved within the allowable interval, terminal B may be blocked or driven to lockout depending on the protection settings.

IV. Autoreclosing With UPS Ride-Through

To evaluate the interaction between automatic reclosing and the voltage ride-through (VRT) capability of large electronic

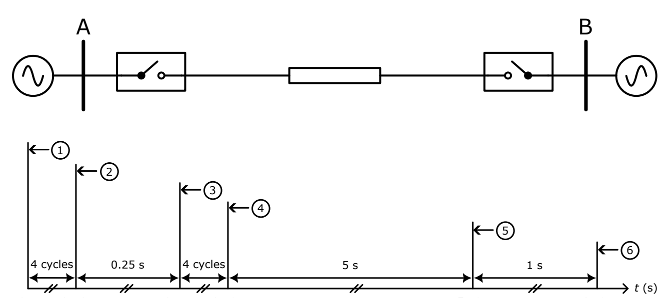

Fig. 2. Autoreclosing sequence of a leader-follower operation. Terminal A is the leader, while Terminal B is the follower.

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loads, two simulation cases were developed using the autoreclosing model described in Section III. The test system shown in Fig. 5 represents a 138-kV transmission line supplying a large data center load modeled as a voltage-sensitive block governed by the ERCOT-proposed UPS VRT curve.

Both cases assume a single line-to-ground (SLG) fault near the midpoint of the line, cleared by high-speed pilot differential protection. The difference between the cases lies in the reclosing speed applied at the leader terminal.

A. UPS Ride-Through Curve

The UPS ride-through characteristic used in this study is shown in Fig. 3. It represents the ERCOT-proposed VRT requirement for data center UPS systems. The curve defines the minimum voltage levels that must be sustained for the corresponding time intervals before a UPS transfers its load to backup supply. Voltages above the curve indicate acceptable operation, while voltages below the curve trigger a UPS transfer.

B. Case 1 – High-Speed Reclosing (0.5 seconds)

The first case considers a high-speed reclosing operation with a 0.5-second dead time. Tripping occurs on all three phases, although the timing is more common for single-pole switching operations, as this allows more time for clearing the secondary arc. Fig. 4 shows the voltages on terminal A and B, as well as the autoreclosing operation of breakers A and B.

At time 0.1 seconds, a SLG fault is applied on the transmission line, which causes the voltage of terminal A to sag to 0.59 per unit, and terminal B to sag to 0.65 per unit. Both breakers trip instantaneously after a four-cycle delay, at 0.167 seconds. Breaker A, after a dead time of 30 cycles attempts its first reclose shot at 0.667 seconds. The voltage at terminal A sags to 0.56 per unit, and since the system has a parallel tie, this fault is reflected to the other bus, even though breaker B remains open.

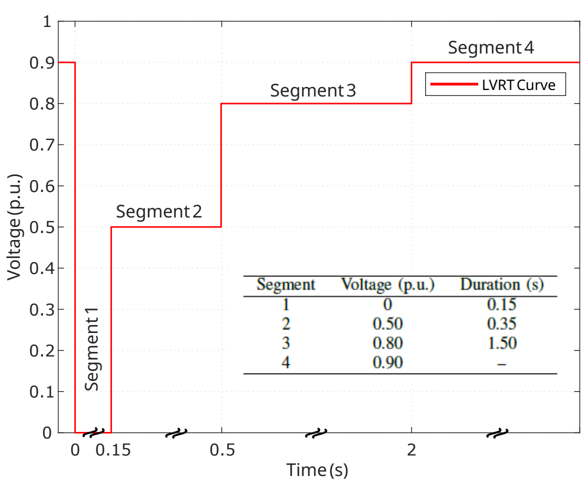

Fig. 3. ERCOT-proposed UPS voltage ride-through curve.

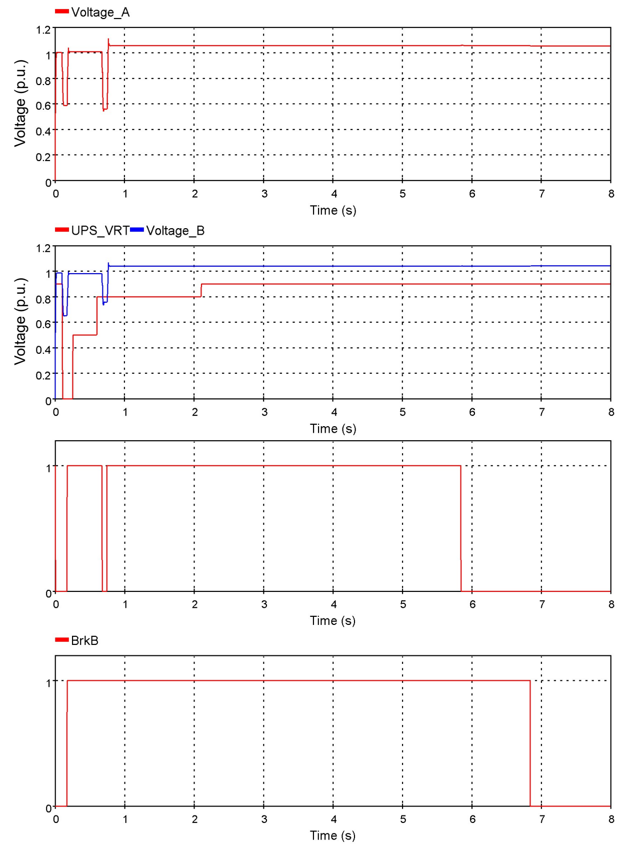

Fig. 4. High-speed reclosing event with a 0.5-s dead time. Top: Terminal A voltage. Second: Terminal B voltage with the UPS VRT curve. Bottom two plots: breaker statuses for Terminals A and B (1 = open, 0 = closed).

This occurs during segment 3 of the UPS ride-through curve, and since the voltage at terminal B sags below 0.8 per unit (sagging to 0.76 per unit), it falls below the threshold of the curve and automatically trips the data center. This causes the voltage to rise to 1.06 per unit at terminal A, and 1.04 per unit at terminal B, clearly showing the overvoltage condition.

This indicates that even with successful reclosing, an extended open interval can trigger UPS transfer if the reclose shot occurs near segment 3 of the UPS ride-through curve. Coordination between reclosing dead time and UPS ride-through settings is therefore essential to prevent unintended disconnection of large data center loads.

C. Case 2 – High-Speed Reclosing (0.25 seconds)

In the second case, the leader terminal executes a high-speed reclosing shot with a dead time of approximately 0.25 s (15 cycles at 60 Hz). In contrast, the follower terminal remains open under voltage supervision. The reclosing logic excludes synchronism check supervision, consistent with common practice for short-duration interruptions.

Until the first reclose shot, the simulation begins exactly as in Case 1. When the first reclose shot occurs, the voltage at terminal A sags to 0.54 per unit, whereas for terminal B it sags to 0.72 per unit. Here, however, the first reclose shot is during

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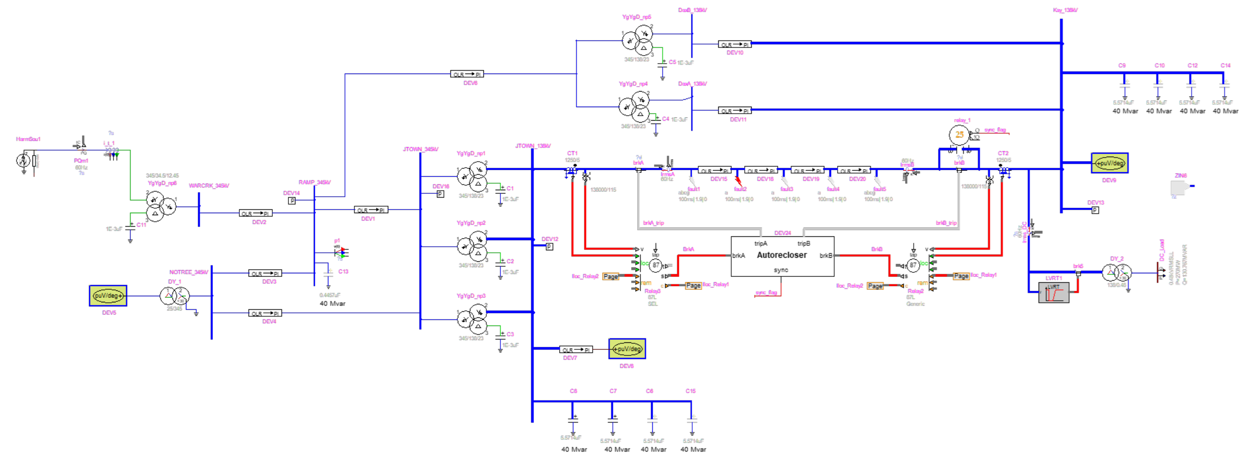

Fig. 5. EMTP model of a 138-kV test system with autoreclosing fault clearing scheme and UPS voltage ride-through model.

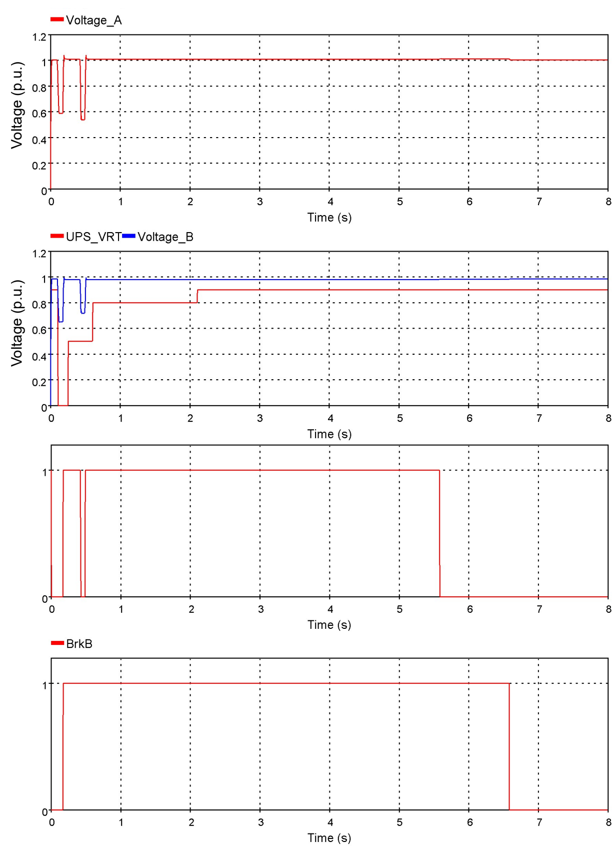

Fig. 6. High-speed three-phase reclosing (15-cycle dead time). Top: Terminal A voltage. Second: Terminal B voltage with the UPS VRT curve. Bottom two plots: breaker statuses for Terminals A and B (1 = open, 0 = closed).

segment 2 of the UPS ride-through curve. The data center rides through the fault and continues operation. Although the disturbance does not trigger transfer, the margin to the curve is narrow, demonstrating that even brief high-speed reclosing can challenge UPS stability during severe transients.

The observed behavior is consistent with the recent NERC Incident Review [3], which reported simultaneous data center load losses coinciding with multiple reclosing attempts on a 230 kV line. These results emphasize the need for utilities and load owners to jointly assess reclosing configurations when connecting large voltage-sensitive facilities.

V. Conclusion

This study demonstrated that automatic reclosing, though essential for restoring transmission service after temporary faults, can adversely interact with voltage-sensitive UPS systems used in large data centers. Simulation results indicated that high-speed reclosing with dead times of 15–30 cycles can approach or cross the proposed UPS voltage ride-through threshold, potentially triggering premature load transfer to backup supply. These observations are consistent with recent NERC incident reviews linking reclosing operations to large-scale data center disconnections. To ensure grid reliability, utilities should evaluate autoreclosing sequences, and align timing parameters with validated UPS ride-through performance.

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