Hybrid islanding detection method based on the rate of change of frequency and load impedance

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Article Info	ABSTRACT
	Interconnection of distributed generation (DG) in distribution system will result in formation of islands in the event of loss of main supply. This scenario is harmful to the power system, hence quick detection is critical to halt the formation of islands. Among the common passive and active detection methods available, the hybrid detection method is identified as the most reliable method. This paper proposes a new hybrid method using the combination of passive and active technique which is the rate of change of frequency (ROCOF) and load impedance, respectively. The passive method works when the value of ROCOF exceeds the threshold value which is set at 0.3Hz/s. The active method works when it detects low value of ROCOF and immediately inject a pre-specified load into the system to increase the ROCOF value up to its threshold value. Simulation study on different case studies is carried out on distribution test system to evaluate the performance of the proposed method. Results show that this method is effective in detecting any events that could result in islanding.

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1. INTRODUCTION

Distributed generation (DG) is a small-scale power generation technology installed in the vicinity of the end users in order to produce electricity. DGs cover any net metered or commercial-scale generation that is connected to the grid at the distribution level. DGs are important as they offer many benefits to the power system such as enhancing the efficiency of electricity supply, reducing distribution and transmission losses and delivering clean and sustainable power to the customers. However, there is a technical issue called islanding which occurs when DG continues supplying power to a part of the distribution system eventhough the connection to the grid is interrupted during catastrophic event.

Islanding can be either intentional or unintentional islanding. Intentional islanding is a properly planned process to improve the system reliability where DG continuously supply power to critical loads in the event of power supply failure from the grid. Readiness of an advanced control scheme in ensuring a smooth changes from grid connected to islanding mode of operation is required. With the controller in place, the grid can sectionalize itself by allowing the DG to supply the islands' load until the main power supply is re-established. On the other hand, unintentional islanding may result in damaging the DG since it operates without proper control mechanism for islanding [1]. Similarly, this is hazardous for utility workers working in the distribution system who are unaware that the network is still operational. This situation usually occurs

when the power is being fed via the DG to the system during loss of main supply form the grid . The exposure to live system can be fatal to the utility workers [2]. Therefore, DG's protection scheme has to detect the islanding situation and immediately disconnect DG from the network. This is referred to as islanding detection method.

Islanding detection methods for both intentional and unintentional islanding are generally classified into local and remote methods. Local method can be further categorized into active and passive methods while remote method is based on communication between the utility and the DGs [3]. Passive method identifies islanding by monitoring the parameters such as frequency, voltage, current, active power, reactive power and harmonic distortion. Many techniques were subsequently introduced with various combination of parameters and settings such as rate of change of positive and negative sequence component [4], rate of change of frequency (ROCOF) [5], rate of change of output power [6], rate of change of voltage and changes in power factors [7], voltage unbalance and total harmonic distortion of current [8] and combinations of four passive parameters [9]. The very recent research considered load angle and mechanical power parameters [10], undervoltage block function [11] and sensitivity of different passive parameters [12]. When the distribution system is islanded, these parameters are significantly affected. Detection relies on the threshold setting for each parameter which will discriminate islanding and non-islanding type of disturbance. However, islanding is difficult to detect when there is minimal power mismatch between generation and load in the islanded system. If the threshold values is too high, islanding might not be detected while if the threshold values is too low, it could result in false tripping of DG.

The weakness of the passive method can be complemented by active method, which can detect the occurrences of islanding even under zero power imbalance between generation and load. Active method identifies a grid failure or islanding by injecting a small signal into the system. This method is applicable for inverter based DGs. Methods such as active positive feedback islanding detection schemes [13], DC/AC inverter acting as virtual capacitor [14], frequency dependent ZIP–Exponential static load model [15], impedance-based analysis of the active frequency drift (AFD) [16], d-axis current injection [17], islanding detection index based on resistance seen from the SSSG terminal with respect to the angular frequency [18] and high-frequency signal injection for multiple parallel-connected inverters based DG [19]. These methods outperforms the passive method but are rather expensive and pose power quality deterioration.

The recent trend of islanding detection using intelligent based and hybrid methods where both associated with passive and/or active method. Intelligent method is based on the application of artificial neural network (ANN), fuzzy logic control (FLC), evolutionary programming (EP), decision tree (DT) [20], adaptive neuro fuzzy inference system (ANFIS) [21], and support vector machine (SVM) [22]. These methods help to classify islanding/non islanding events based on training and testing data obtained from the simulation/experiment conducted on the test system. Testing on different types of faults based on passive parameter is rigorously carried out to generate huge amount of data. As a result, the classification is accurate with a nearly zero non-detection zone (NDZ) and detection is reached in a very short time. However, any changes made on the test system such as network expansion, will cause the need of a new set training data for classification process.

Introduction of hybrid islanding detection method [23] can overcome the shortcomings in passive or active method approach. It combines the advantages of both method to offer more effective result compared to passive/active method alone. Hybrid method proposed in the literatures considered combination of voltage unbalance and frequency set point [24], average rate of voltage change and real power shift [25], voltage unbalance (VU) and high-frequency (HF) impedance [26], dynamic characteristics of synchronous generator and signal processing technique [27], voltage unbalance and total harmonic distortion (VU/THD) and bilateral reactive power variation (BRPV) [28], rate of change of exciter voltage (RCEV) and open-close circuit breaker (OCCB) at a DG connection point [29]. In addition, there is also a new approach of hybrid method using combination of active, passive and communication technique [30]. Each method has different detection performance depending on the chosen combination. The active technique is normally adopted when passive technique alone is unable to detect islanding scenario particularly during minimal power mismatch. So far, the hybrid method employs the combination of a new type of passive method with an advanced active method. However, the research work on hybrid method using the ROCOF which is commonly adopted by utility companies has not been explored in detail. This is important as a comprehensive investigation is required on the practicality of applying proposed hybrid method to existing islanding detection technique.

This paper proposes a new hybrid method which combines ROCOF as the passive method and injection of load impedance as the active method. ROCOF is chosen since it is commonly used as the main protection system in distribution system. ROCOF operates when it detects islanding based on the rate of changes of frequency that exceeds the threshold limit. The load impedance is injected to the system when it detects a small value of ROCOF. The injection will increase the value of ROCOF up to the specified limit. This will ensure that the islanding detection is successful even there is a small power mismatch. The main

contributions of this studies are: 1) quick islanding detection which is less than 20ms, 2) effective detection of islanding and non-islanding event, and 3) employs a simple method using standard parameter measurement. This method is modelled and simulated using PSCAD/EMTDC simulation tools. In order to evaluate this method, there are seven case studies introduced which are loss of main, fault at adjacent line (single line to ground fault, line to line to ground fault, and three phase fault) and fault near to DG (single line to ground fault, line to line to ground fault, and three phase fault). This paper is organized as follows in which the proposed hybrid detection method and test system are elaborated in section 2, result and discussion are explained in section 3 and finally conclusion is drawn in section 4.

2. RESEARCH METHOD
The hybrid islanding detection method applied in this study uses ROCOF as a passive method and the injection of load impedance as the active method. The modelling of the proposed method and test system are described in the following section.

2.1. Modeling proposed method
Two modules comprising of active and passive method are developed for the proposed hybrid method as depicted in Figure 1. Passive and active module are located in the DG protection unit and at the generator bus, respectively.
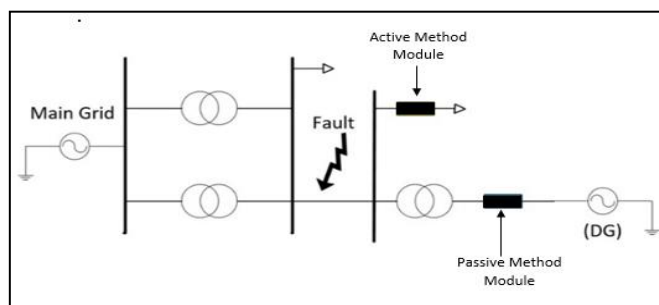

Figure 1. Principal operation of the proposed method

The development concept of the hybrid method is shown in Figure 2. The passive method module is used to continuously monitor the ROCOF value which is taken from the speed measurement of DG. The proposed method detects any islanding event whenever the ROCOF value exceeds the specified threshold. A tripping signal is subsequently sent to circuit breaker of the DG's protection system thus prohibiting the DG from supplying the load. Active method module will only be activated to inject an additional load to the system whenever it detects ROCOF value less than the threshold value. Details of the islanding detection process is described in Figure 3.
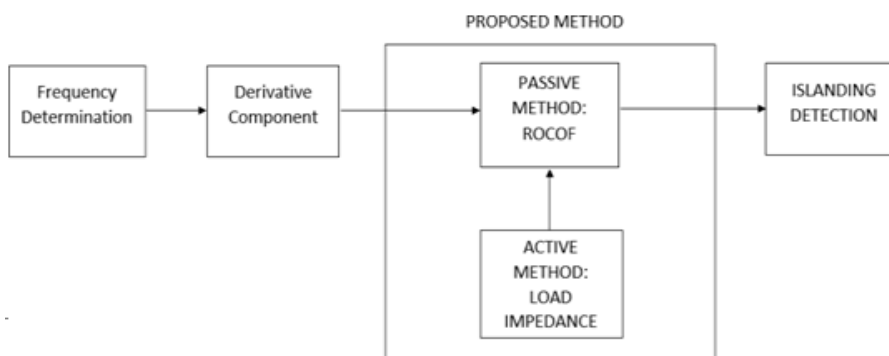

Figure 2. Block diagram of the proposed method

The process starts with the determination of frequency from the speed measurement of DG. Then, derivative component is used to calculate the rate of change of frequency (ROCOF). The active and passive method are designed specifically for detection purposes considering the ROCOF as the input. The script for designing the module is written using FORTRAN programming language. The passive module is designed based on the comparison between the calculated ROCOF value and ROCOF threshold setting. Detection module will be triggered once the ROCOF value surpass the threshold value. The common setting for ROCOF threshold is between 0.1Hz/s to 1Hz/s [12]. In this study, the threshold value of 0.3Hz/s is used. Meanwhile, the output of the active method module will send a signal to inject a load with a value of 330kW to the system when the magnitude of the calculated ROCOF is less than 0.3Hz/s. The value of the injected load cannot be too high because it will cause system interference. The value of 330kW is deemed suitable for the system is determined from several tests conducted for LOM as recorded in Table 1. The value of active load highly depends on the power imbalance the moment system experiences disturbance. Lower power imbalance of less than 270MW, would require an injection of a large load value of 540kW. High value of load is infeasible for islanding detection purposes as it would incur high cost. The load injection for power imbalance greater than 280MW would result in a steep increase of ROCOF value to more than 0.3Hz/s, hence triggering islanding detection mechanism and subsequently the DG breaker is tripped.
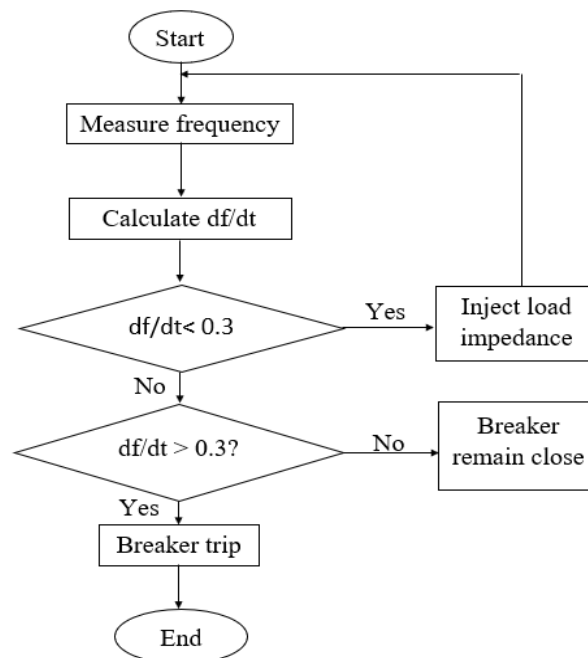
Figure 3. Flow chart of the proposed islanding detection method

Table 1. Analysis of the islanding detection on different range of ΔP for various load values

Range of ΔP(kW)	Load(kW)	Detect Islanding	Preferable
90–270	150kW	×	
	330kW	×	
	540kW	✓	Prefer
280–430	150kW	×	
	330kW	✓	Prefer
	540kW	✓	
440–540	150kW	✓	Prefer
	330kW	✓	
	540kW	✓	

2.2. Test network

The test system shown in Figure 4 was modelled using PSCAD software. The 7-bus system operates at 50Hz, 33kV, and includes a 100MVA generator as main supply. As shown in the Figure 4, there are two step-down transformers of 33/11 kV and 11/3.3 kV rated at 20MVA and 2MVA respectively. The 2MVA

transformer is placed at the end of the distribution line where DG is located. The DG is modelled as a hydro turbine generator rated at 2 MVA. The loads connected to the system are static loads.
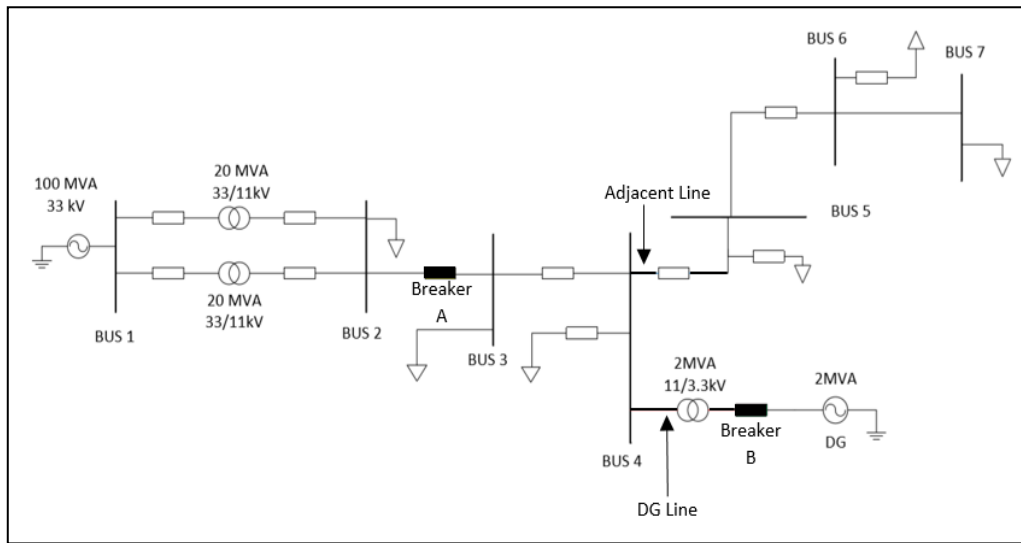

Figure 4. 7-bus test system

3.   RESULT AND ANALYSIS
In order to evaluate the effectiveness of the proposed method, three case studies are simulated based on the 7-bus test system. The three case studies are:
− Case 1: Loss of main
− Case 2: Various fault at line connected to DG (DG Line)
− Case 3: Various fault at line adjacent to DG at line 4-5

The faults considered in this study are single line to ground fault, line to line to ground fault, and three phase fault. Case 1 which is loss of main, a signal is sent to open breaker A to disconnect the main supply at t = 10 seconds. Case 2, three different types of faults are applied at line connected to DG as indicated in Figure 4. As for case 3, three different types of faults are applied at adjacent line (line 4-5) as indicated in Figure 4. Results for the three case studies are tabulated in Table 2.

Table 2. Breaker trip status for all three cases

Cases	Type of Events	Breaker B Condition
1	Loss of main	TRIP
2	Single line to ground fault	TRIP
	Line to line to ground fault	TRIP
	Three phase faults	TRIP
3	Single line to ground fault	NOT TRIP
	Line to line to ground fault	NOT TRIP
	Three phase faults	NOT TRIP

3.1. Loss of main
The system frequency immediately increases in response to the disconnection of main grid from the distribution network. Based on Figure 5, the frequency of DG increases until it hits 71Hz then gradually drops to 30Hz. The frequency increment contributes to the increment of the ROCOF value. As can be seen in Figure 6, the ROCOF reading at t=10 seconds exceeds the ROCOF threshold which has been set at 0.3Hz/s. As a result, a signal is sent to trip the breaker B. The islanding detection mechanism verifies that loss of main is islanding scenario and proceeds to trip breaker B causing the DG to shut down. The change of active power due to the islanding caused the frequency drops and unstable. Only passive method works for this case since the ROCOF value is greater than the threshold value. The high value of frequency and df/dt is due to a large power imbalance between generation and load the moment system is disconnected from the main.
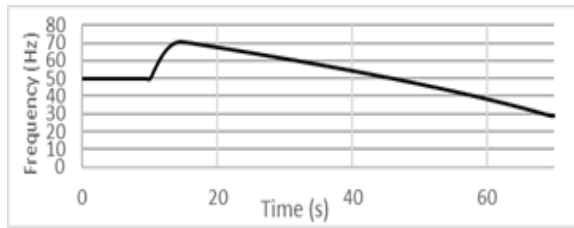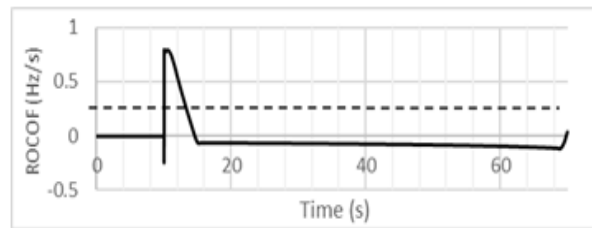
Figure 5. Frequency of DG for loss of main

Figure 6. ROCOF measurement for loss of main

3.2. Fault at DG line

As mentioned earlier, three types of faults are simulated which are three phase fault, single line to ground fault, and line to line to ground fault. The fault is simulated at t=10 seconds with 0.05 seconds of fault duration. For all type of faults, the reading of ROCOF exceeds the ROCOF's threshold value which causes breaker B to trip. Figures 7 and 8 shows the frequency response and ROCOF value respectively when a three-phase fault is applied to the system. Eventhough the fault duration is very short, huge impact to the system frequency can be seen following the fault. The response is almost similar to the response due to loss of main. The hybrid module manages to successfully detect the islanding scenario due to the fault location location is near to DG which contributes to the high ROCOF value.
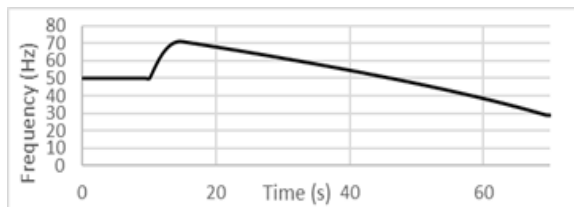

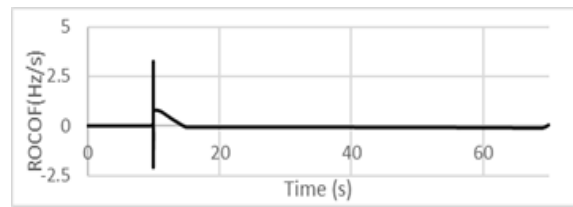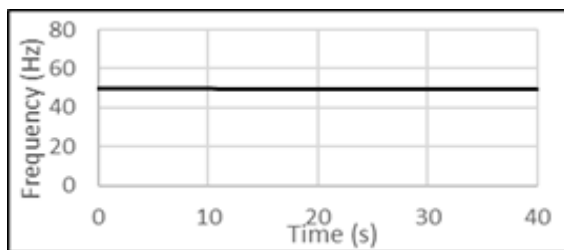Figure 7. Frequency of DG for three phase fault

Figure 8. ROCOF measurement for three phase fault

3.3. Fault at adjacent line (line 4-5)

The adjacent line is located at the same bus with the DG line. The fault setting is set similar to case 2. Results show that breaker B does not trip for all three types of faults. The system frequency stays at 50Hz following the fault as shown in Figure 9 (a). This causes the ROCOF to remain at zero value even after fault as shown in Figure 9 (b). The fault does not impact the system since it is applied at the load side as it does not interfere the power flow from power supply to DG.

(a)

(b)

Figure 9. These figures are; (a) frequency, (b) ROCOF measurement for three phase faults at adjacent line1

3.4. Comparative analysis

Comparative analysis is carried out to analyse the advantage of having an active method in the proposed hybrid method. Simulation is performed for case 1 by using two different detection method: 1) passive method and 2) hybrid method module. The simulation is carried out for a small value of power mismatch, ∆P. Based on results shown in Figure 10, the reading of ROCOF for passive method does not even

reach the threshold value since ΔP is small. However, with the proposed hybrid method which combines passive and active method, the injection of load impedance from active method pushes the reading of ROCOF to reach the threshold value. As a result, the proposed method able to detect islanding for a small value of power imbalance as recorded in Table 3. This proves that the hybrid detection method gives better performance than passive method in detecting islanding event. Moreover, non-detection zone (NDZ), which is one of the most important criteria for islanding detection method is also assessed in identifying the area that both methods fail to detect islanding scenario. Rigorous testing is carried out to identify an accurate NDZ for both methods. The NDZ shown in Figure 11 obviously differentiate the accuracy of detection for both methods where the hybrid method has a smaller NDZ compared to the passive method. The result indicates that more islanding events can be detected by hybrid method compared to passive method, thus increasing the islanding detection reliability. In terms of detection time, the proposed hybrid method would detect islanding event in 35 ms and 70 ms for passive and hybrid method respectively. This indicates that the proposed method is better compared to other methods listed in Table 4. However, in real world application, the time taken may vary accordingly depending on the signal and communication delay.
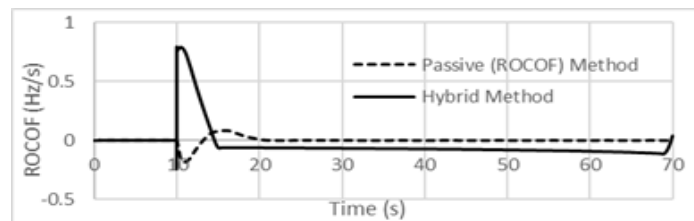

Figure 10. Comparison of ROCOF between hybrid method and passive method

Table 3. Result of loss of main with hybrid and passive method

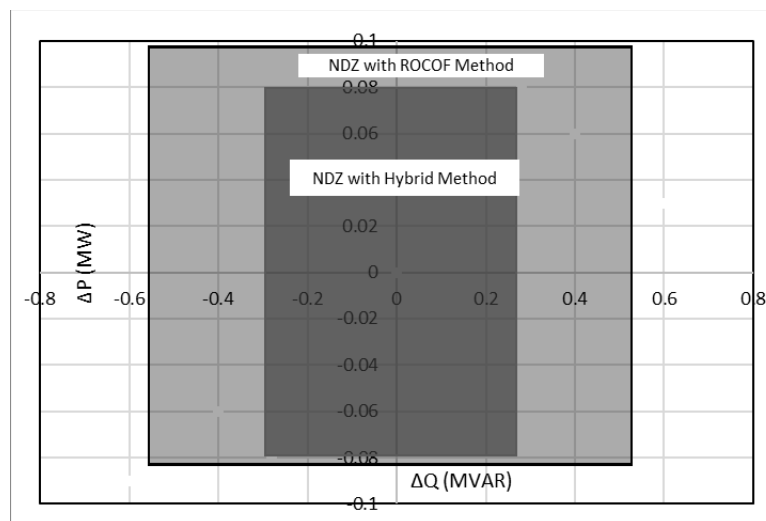|	Cases	Breaker B Condition
Loss of main	Hybrid Method	TRIP
	Passive Method	NOT TRIP

Figure 11. NDZ for ROCOF and hybrid methods

Table 4. Comparative analysis on islanding detection time

Detection Method	Detection time (ms)
Undervoltage block function [11]	136.2
Voltage Unbalance and Total Harmonic Distortion of Current [8]	129
Rate of Change of Exciter Voltage with Circuit Breaker Switching Strategy [29]	100 (passive)
	300 (hybrid)
Proposed method	35 (passive)
	70 (hybrid)

4. CONCLUSION

This paper presents a hybrid islanding detection method by using the rate of change of frequency (ROCOF) and the injection of load impedance. Several case studies have been simulated on the test distribution system to assess the effectiveness of the proposed method. Results proved that the method effectively detected all event that could result in islanding. Comparison studies including the NDZ assessment with the passive method further validated the islanding detection performance of the hybrid method.

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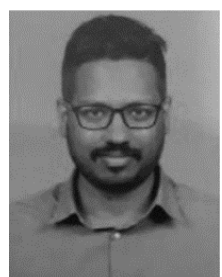
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