

## OPF including TCSC devices using FACTS program software

**Abstract.** The solutions FACTS (Flexible Alternating Current Transmission Systems) allows network operators to increase the capacity of the existing stock, while maintaining or improving the operating margins necessary for grid stability. This increases the amount of energy delivered to load centers with minimal impact on the environment, with projects much faster to implement and reduced capital spending compared to other solutions. The objective in this paper is to evaluate and compare the values in the cost of power generation with and without TCSC transit controller (Thyristor Controlled Series Capacitor). In addition, we present a new idea of presenting software that we developed and appointed: FACTS programmer

**Streszczenie.** W publikacji oszacowano i porównano koszty wytwarzania energii elektrycznej w sieci z urządzeniem typu FACTS (ang. Flexible AC Transmission System) opartym na pojemnościowym kompensatorze mocy (ang. Thyristor Controlled Series Capacitor) i bez niego. Przedstawiono także opracowane nowe oprogramowanie o nazwie FACTS Programmer. (Wykorzystanie oprogramowania FACTS Program w badaniu kompensatorów typu TCSC)

**Keywords:** Economic dispatch, FACTS, TCSC, Delphi, Matlab.

**Słowa kluczowe:** Ekonomiczny model dystrybucji energii, FACTS, TCSC, Delpi, Matlab

### Introduction

Recent years a decline in investments in infrastructure related to the transmission was observed. It is particularly due to the pressures of the environmental community and the red tape that make the construction of new transmission lines increasingly difficult or impossible.

In this context it is interesting to the system operator to have a way to control power flows in the lines so that the existing transmission system can be operated in the most secure as possible.

Until the late 1980's, the only way to perform these functions were electromechanical devices: the phase shifter adjustable support for the control of active power, the inductors and capacitors for circuit switched maintaining the voltage and reactive management.

However, problems of wear and their relative slowness do not operate these devices more than a few times a day and are therefore difficult to use for a continuous flow of power.

Another technique for adjusting the active power flows using power electronics has been proven. This is the current transmission converter stations with back-back. This technology is however very expensive and its use is mainly restricted to the interconnection of networks operating at different frequencies or whose methods of adjustment are not the same as well as transport over long distances electrical [1].

The paper is organized as follow: Section II presents a brief overview of Optimization the existing plants with FACTS devices.

### Overview on the optimisation of existing facilities with FACTS devices

There are over one thousand installations FACTS (Flexible Alternating Current Transmission Systems) around the world, which is an important service for decades. FACT is a facility designed for a general life of 30 years.

FACTS devices are used not only to prolong life and enhance existing facilities. Other possible applications:

- Changes to the electricity grid, for example: mandatory or desirable to change the power short-circuit, necessary to increase the power flow, etc..
- Reap the benefits of technological advances made since originally installed.
- Increase the availability of the system or replace an obsolete technology. Problem type: shortage of spare parts or need to simplify maintenance.

- Adding Features to install, for example: new features control center or protection, telecommunications, diagnosis, etc..
- Development of environmental constraints or regulation, for example: noise, seismic certification, aesthetic perception, space saving, etc.. [2]

### FACTS classification by mode of network connection

How to connect to the network is an essential feature that largely determines the mode of action of the controller. There are several classes, among them we have:

#### Controller type Serial

These systems insert series impedance in the connection or a variable voltage source. Their principle of action is always reducible to the injection of a power series in the binding, since the product of the impedance inserted by the current injection well is a tension.

Of these systems will, in functional terms, model by a variable voltage source. If this is not the case, the system must provide or absorb the reactive power. If this is not the case, the system also implements the active power.

In practice, such controllers' type series are made in various ways: by the banks of capacitors or variable inductors stands by mechanically switched or thyristor electronic switches or by variable impedance continuously implementing a thyristor dimmer switch, or finally, by injecting a voltage in series with a transformer.

#### ➤ The Controlled Séries Capacitor, or CSC:

This system uses fixed values of capacitors placed in parallel inductors controlled by a variable current thyristors, so as to make continuous adjustment of the capacitive or inductive compensation respectively above and below the resonance frequency. The block diagram of such a system and its characteristic adjustment are shown in Figure 1 and Figure 2.

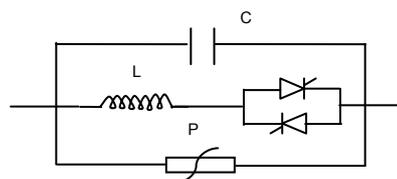


Fig.1 Diagram of an ASC or TCSC

with: P = overvoltage protection

$$(1) \quad Z = j \frac{\omega L}{1 - \omega^2 LC} \quad [\Omega]$$

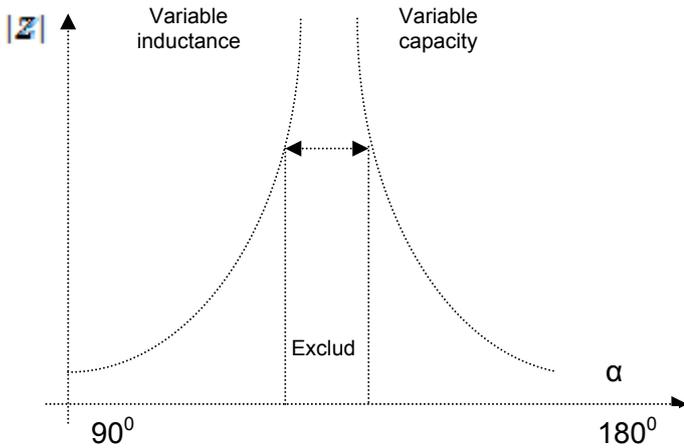


Fig. 2. Characteristic adjustment of an CSC or TCSC

At present the existing achievements, only the capacity variable is usually implemented.

Control includes, in most cases, cascade control slow the flow of power and a rapid control, for example, the frequency difference between interconnected areas for damping oscillations of power [3].

### Economic dispatch

Producers of electrical energy determine experimentally the curves giving the cost of production of each group according to the power he sells. The function associated with these curves is a polynomial of degree "n". In practice, most often it is presented as a polynomial of second degree. [4]

$$(2) \quad F(P_{G1}) = a_1 P_{G1}^2 + b_1 P_{G1} + c_1$$

The function F (PG1) is known only in discrete form, that is to say, from a number of points. For this reason it makes use of interpolation methods to determine the coefficients a<sub>1</sub>, b<sub>1</sub>, c<sub>1</sub> that are specific to each production unit.

Minimizing the total cost function of power generation is a task which is presented as follows:

$$(3) \quad \text{Min} \{ F = \sum_{i=1}^n F_i(P_{Gi}) \}$$

Subject to constraints:

$$(4) \quad \sum_{i=1}^{ng} P_{Gi} - P_{ch} - P_L = 0$$

$$(5) \quad P_{Gi \min} \leq P_{Gi} \leq P_{Gi \max}$$

$$(6) \quad \sum_{i=1}^{ng} Q_{Gi} - Q_{ch} - Q_L = 0$$

$$(7) \quad Q_{Gi \min} \leq Q_{Gi} \leq Q_{Gi \max}$$

$$(8) \quad V_{i \min} \leq V_i \leq V_{i \max}$$

$$(9) \quad |\delta_{ij}| \leq \delta_{ij, \max}$$

Solve this problem with all these constraints is not feasible for a large network with multiple nodes and generally interconnection lines, so it is necessary to simplify the problem. We have omitted the constraints (8) and (9), assuming that all nodes have roughly the same voltage module and phase. Constraints (6) and (7) can be ignored, since the reactive power does not have a significant impact on the cost function.

The term transmission losses according to the power generated is given by [5]:

$$(10) \quad P_L = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_{Gi} B_{ij} P_{Gj}$$

### Presentation of software FACTS program

#### Primary interface

FACTS Program V.1.0 software is made in two parts:

1 - Delphi interface.

2- program that addresses the difficulty set out above, written in Matlab.

In this section we try to describe the representation and the different steps that allow you to run this software from one window to the next.

First Window: This window shows the name and version and other information specific to the software in <<ABOUT>>.

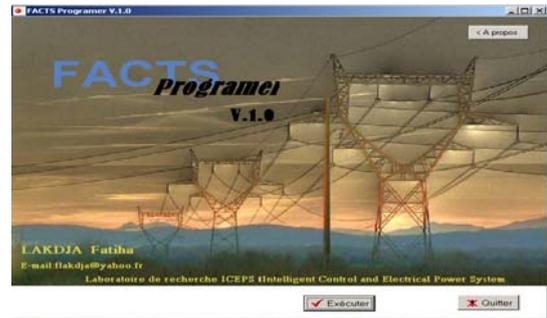


Fig.3.: FACTS program interface

#### Menu of different options

Second window: In general what follows is a set of choices to be made by the user for a specific result. In this window the user must specify the type of network and type of FACTS.

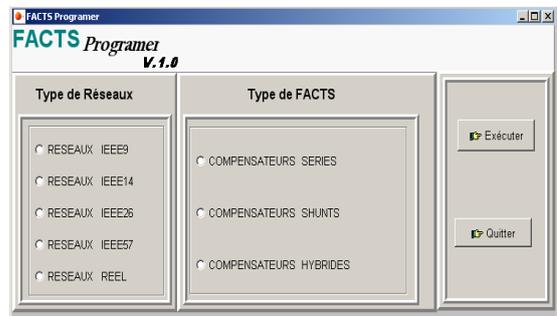


Fig.4. Second window of FACTS program.

Third window: In this third window, the user will be further choice he must know in order to achieve a program.

A. Case study of insertion of FACTS device in a network of electric power:

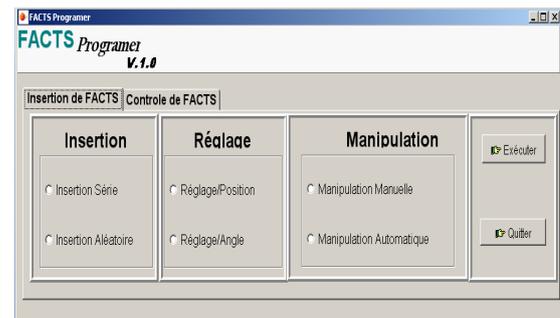


Fig.5. Third window FACTS program.

B. Case study of control of FACTS devices in a network of electric power:

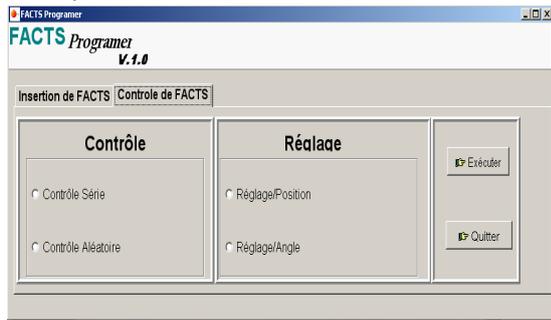
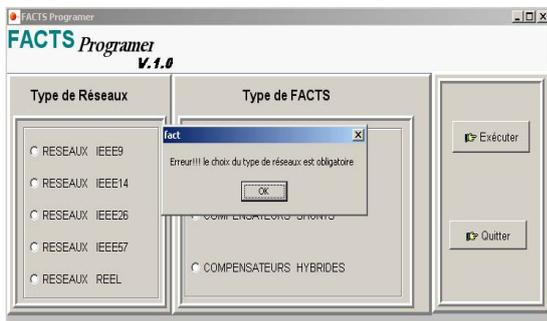


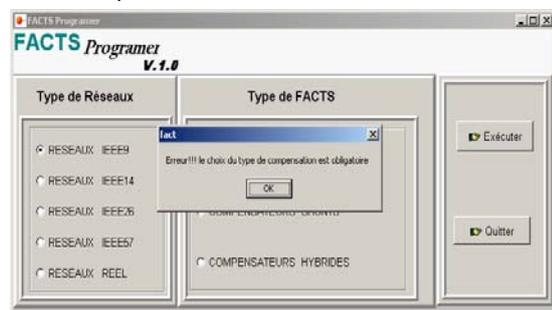
Fig.6. Fourth window FACTS program.

Note: During execution, we can find error messages if the user leaves the principle of execution, for brevity we lemons that two of the possible cases and regency of this software.

➤ Example 1



➤ Example 2



**The proposed solutions**

➤ The methodology consists of finding the optimal configuration from one or more solutions (depending on the algorithm used) and try to improve over successive iterations. Evaluation of the quality of a solution is by means of calculation distribution powers classics.

According to the modeling of TCSC, the device changes the nodal admittance matrix of the network. It is from that of the changed load flow is calculated.

➤ The optimization method used between the class of nonlinear programming with constraints and loss variables.

➤ Presentation of software that performs an interface on Windows, with a menu object-oriented, easy to handle, easy to perform and can call a program in Matlab: which we named FACTS Programmer V.1.0

**Simulations and results**

The proposed algorithms in the software are applied in a grid IEEE 26 nodes [6] is a network selected from a number brought into the FACTS program.

Similarly, there are several algorithms for this paper we have chosen:

**Algorithm 1:** "Automatic Control Series by Position," with one TCSC and two TCSC.

A. Simulation 1

➤ Parameters of TCSC

1) The base value is:  $S_b = 100$  MVA

2) The parameters corresponding to the selected controller transits TCSC<sub>1</sub> are:

- Frequency:  $f = 50$  Hz
- The inductive reactance:  $X_{L1} = 0003$  pu
- The capacitive reactance:  $X_{C1} = 0.001$  pu
- Angle Boot alpha  $\alpha$ :

$$\alpha_{1min} = 142^\circ, \quad \alpha_{1max} = 180^\circ, \quad \alpha_1 = 143^\circ$$

B. Simulation 2

➤ Parameters of the two TCSC

1) The base value is:  $S_b = 100$  MVA

2) The parameters corresponding to the selected controller transits TCSC<sub>1</sub> and TCSC<sub>2</sub> are:

- Frequency:  $f = 50$  Hz
- The inductive reactance:  $X_{L1} = 0003$  pu
- The capacitive reactance:  $X_{C1} = 0.001$  pu
- The inductive reactance:  $X_{L2} = 0002$  pu
- The capacitive reactance:  $X_{C2} = 0.001$  pu
- Angle Boot alpha  $\alpha$ :

$$\alpha_{1min} = 142^\circ, \quad \alpha_{1max} = 180^\circ, \quad \alpha_1 = 143^\circ, \quad \alpha_2 = 143^\circ$$

Table 1. Simulation result of algorithm 1

Results	without TCSC	with TCSC <sub>1</sub>	with TCSC <sub>1</sub> and TCSC <sub>2</sub>
Choice of angle (degree)	-	143	-
Ideal position (k-m)	-	(16-17)	-
Choice of angle (degree)	-	-	143 et 143
Ideal position (k-m)	-	-	(16-17)
Total losses (MW)	12.807	12.7786	12.7446
Total Cost (\$ / h)	15447.72	15447.38	15446.96
Lambda $\lambda$ (\$ / MWh)	13.538113	13.537820	13.537455
P <sub>1</sub> (MW)	447.6919	447.5630	447.4143
P <sub>2</sub> (MW)	173.1938	173.1583	173.1197
P <sub>3</sub> (MW)	263.4859	263.6850	263.9128
P <sub>4</sub> (MW)	138.8142	138.9175	139.0345
P <sub>5</sub> (MW)	165.5884	165.4741	165.3404
P <sub>26</sub> (MW)	87.0260	86.9740	86.9163

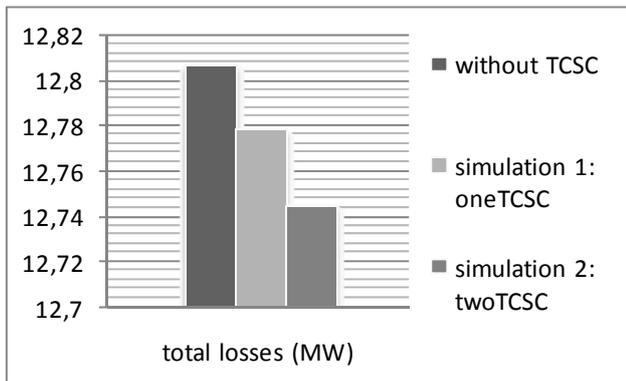
**Interpretation of results**

Simulation 1: The algorithm "insert serial position automatically" for a network with 26 nodes and with the introduction of the parameters of TCSC<sub>1</sub>, the location of the optimal location is the branch (16-17).

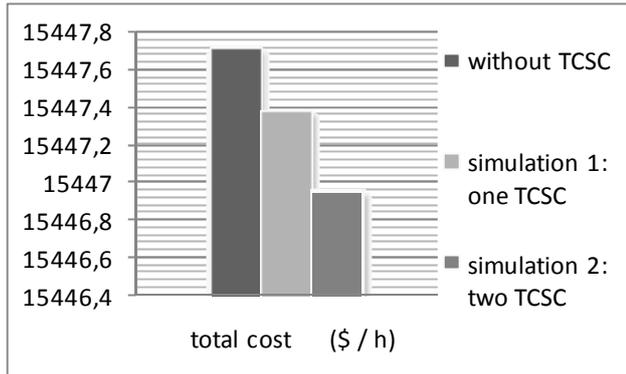
The best location has a significant and effective loss of the value  $P_t = 12.807$  MW to the value  $P_t = 12.7786$  MW, followed by the decrease in other factors, the cost: value 15,447.72 \$ / h to the value 15,447.38 \$ / h, the factor lambda: from 13.538113 \$ / MWh to the value 13.537820 \$ / MWh, and the reduction of power is optimal without exceeding the limits imposed by the test of optimization.

Simulation 2: The second simulation, we were able to verify the theory of integration of two or more series TCSC.

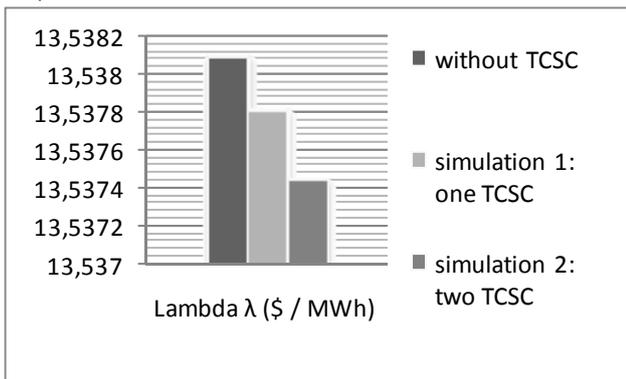
We noted that the results of the losses, the cost factor and lambda were better compared to simulation 1. Hence the validity of our proposed algorithms.



Graph 1: Total losses for a 26 IEEE Network



Graph 2: Total cost for a 26 IEEE network



Graph 3: Lambda Factor for a 26 IEEE Network

**Algorithm 2:**

"Control Series by angle adjusting Automatic": with one TCSC and two TCSC.

**A. Simulation 1:**

➤ Parameters of TCSC

- 1) The base value is:  $S_b = 100$  MVA
- 2) The parameters corresponding to the selected controller transmits TCSC<sub>1</sub> are:

- Frequency:  $f = 50$  Hz
- The inductive reactance:  $X_{L1} = 0.003$  p.u
- The capacitive reactance:  $X_{C1} = 0.001$  p.u
- Angle Boot alpha  $\alpha$ :  
 $\alpha_{min} = 142^\circ, \alpha_{max} = 180^\circ$

We inserted the TCSC1 in the branch (16-17).

**B. Simulation 2:**

➤ Parameters of the two TCSC

- 1) The base value is:  $S_b = 100$  MVA
- 2) The parameters corresponding to the selected controller transmits TCSC<sub>1</sub> and TCSC<sub>2</sub> are:

- Frequency:  $f = 50$  Hz
- The inductive reactance:  $X_{L1} = 0.003$  p.u

- The capacitive reactance:  $X_{C1} = 0.001$  p.u
- The inductive reactance:  $X_{L2} = 0.002$  p.u
- The capacitive reactance:  $X_{C2} = 0.001$  p.u
- Angle Boot alpha  $\alpha$ :  
 $\alpha_{min} = 142^\circ, \alpha_{max} = 180^\circ$

We inserted the TCSC1 in the branch (16-17).

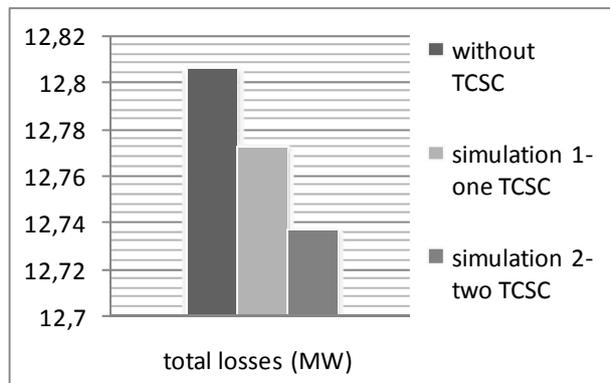
Table 2. Simulation result of algorithm 2

Results	without TCSC	with TCSC <sub>1</sub>	with TCSC <sub>1</sub> and TCSC <sub>2</sub>
Choice of location (k-m)	-	(16-17)	-
Best Angle (degree)	-	174.3	-
Choice of location (k-m)	-	-	(16-17)
Best Angle (degree)	-	-	147.7
Total losses (MW)	12.807	12.7734	12.7372
Total Cost (\$ / h)	15447.72	15447.31	15446.88
Lambda λ (\$/ MWh)	13.538113	13.537765	13.537374
P <sub>1</sub> (MW)	447.6919	447.5399	447.3833
P <sub>2</sub> (MW)	173.1938	173.1522	173.1121
P <sub>3</sub> (MW)	263.4859	263.7205	263.9599
P <sub>4</sub> (MW)	138.8142	138.9359	139.0585
P <sub>5</sub> (MW)	165.5884	165.4535	165.3122
P <sub>26</sub> (MW)	87.0260	86.9648	86.9047

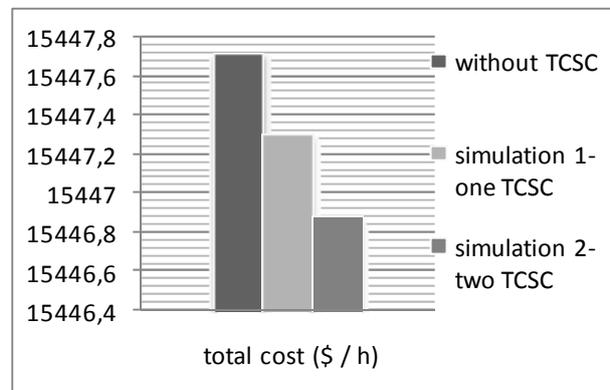
**Interpretation of results**

In the second algorithm named "Series control angle adjustment Automatic", we inserted in the TCSC controller line (16-17), the results obtained is an improved system for better adjustment alpha (174.3 degrees) automatically find.

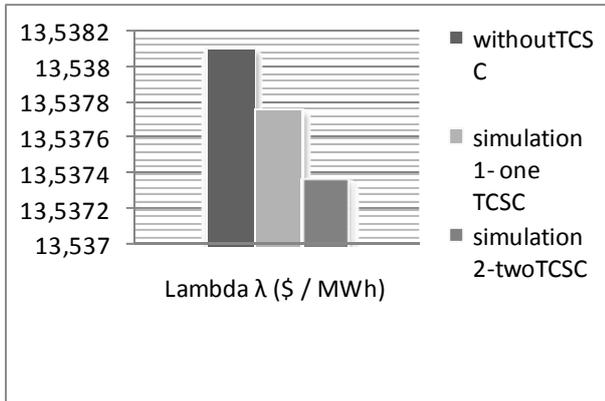
The insertion of two TCSC controllers in the same line (16-17), the results improved significantly for an angle of alpha = 147.7 degrees leveling found by Algorithm 2.



Graph 4: Total losses for a 26 IEEE network



Graph 5: Total cost for a 26 IEEE network



Graph 6: Lambda Factor for a 26 IEEE network

## Conclusion

The contribution our work is involved in the issue, or we thought of designing software called "FACTS Program" which includes two types of studies:

➤ The first is the realization of a program that allows us to make the global study of the insertion of TCSC for electric power systems in the field of series compensation. But this insertion provides information on the different possibilities to place the device and analyze the results in relation to many theoretical studies already made.

➤ The second point is similar to the practice because we have designed a program that analyzes the electrical system and control according to the criteria imposed in reality. This program provides diverse accessibility, to control the power flow, to minimize the line losses and total system and especially to minimize the cost of operating the electric power system.

In the end the usefulness of FACTS program is to:

- Bring together all our programs made;
- Give the operator the choice of study of FACTS devices for optimal location in a network of electric power.
- Allow the operator to understand how the FACTS, when the squares have a network of electric power.
- Provide a working tool to facilitate the search for future research students.

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