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Paper Authors

D.SIDDARDHA, Y.V BALARAMA KRISHNA RAO
Krishna Chaitanya Institute of Technology & sciences Prakasam (Dt); A.P, India.
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DESIGN AND SIMULATIONS OF SUPER-CAPACITOR BASED POWER QUALITY IMPROVEMENT BY USING UPQC

[1]D.SIDDARDHA, [2]Y.V BALARAMA KRISHNA RAO

[1]M-tech Student Scholar,Department of Electrical & Electronics Engineering,Krishna Chaitanya Institute of Technology & sciences Prakasam (Dt); A.P, India.

[2]Professor&Hod,Department of Electrical & Electronics Engineering,Krishna Chaitanya Institute of Technology & sciences,Prakasam (Dt); A.P, India.

Abstract- This paper introduces the integration of unified power quality conditioner with the super-capacitor for improving the power quality at the supply mains. This work described the unified power quality conditioner principles and power restoration for balanced or unbalanced voltage sags or swells in a distribution system. This method proposes a typical configuration of unified power quality conditioner for compensating sag or swells conditions for three phase system that consists of a DC/DC converter supplied by a super-capacitor at the DC link. A suitable series-shunt controller is employed for controlling the unified power quality conditioner under balanced or unbalanced load currents is also presented. On the other hand, Super Conducting Magnetic Energy Storage (SMES) are one of the most promising super conducting devices, considering its possible applications in power system. The proposed model was developed and tested in the MATLAB/SIMULINK environment.

Keywords—UPQC; SMES; Power Quality, super capacitor.

I. INTRODUCTION

The modern equipment's that are used in home are very sensitive and prone to harmonics as well as voltage disturbances with poor power factor. The power quality problem is also due to the different faults conditions occurring on the power system network. These conditions cause voltage sag or swell in the system and malfunctioning of devices which damages the sensitive loads [1-2]. The mitigation of these on the source and load sides is most important for improving the reliability as well as performance on the system. Unified Power Quality Conditioner (UPQC) is expected to be one of the most powerful solutions to large capacity loads that are sensitive to the changes in supply voltage, flicker or imbalance. The UPQC has a single topology that combines series active power filter and shunt active power filter with a common DC link. These two are connected in a back to back configuration. Shunt active power filter compensates all current related distortions and series active power filter compensates all voltage related distortions [3-4]. The compensation can be done effectively, if there is an effective DC link. The operation of both series active power filter and shunt active power filter are based on voltage source converter technique. The shunt compensator takes care of reactive power compensation, current harmonic compensation, load unbalance compensation and power factor improvement [5]. The series compensator acts for voltage harmonics, voltage sag or swells, flickering etc., with the harmonic isolation between load and supply. The super-capacitor is used as a battery storage device across the DC link for short time duration [6]. A configuration with STATCOM-super capacitor energy storage system is used to enhance power system stability and quality [7]. Super capacitors are also find applications in metro vehicles and hybrid electric vehicles [8], also in traction [9]. The battery has a high storage capacity but unreliable and flywheels requires a lot of maintenance. The discharge rate is slower in batteries because of slower chemical process. But now the future is turned to higher rate of charging and discharging the energy which is possible with the super capacitors. The super capacitors stores less energy however the power transfer capability is high compared to the conventional batteries. The rate of discharge while compensation is fast and it takes only a small current for charging [10-12]. Use of super capacitor is proposed in UPQC scheme as it is characterized by less weight; faster charge/discharge cycle time, higher power density, higher efficiency and almost maintenance free.This Integrated unit is developed to enhance the capability of the UPQC and to maintain a high quality voltage, current and power factor at the point of common coupling. This paper concentrates on both series and shunt inverters functioning on voltage related issues like sag, swell and flickering etc. and reduction of harmonics and reactive power control [13]. This paper suggests a new form of UPQC, DC/DC converter and energy storage system. The operation of the intended system was observed through MATLAB environment using Simulink.

II. Unified Power Quality Conditioner

In recent years, FACTS has appeared as solution of many PQ problems. The FACTS concepts applied in distribution systems has resulted in a new generation of compensating devices. A UPQC is the extension of the UPFC concept at the distribution level. UPQC is the integration of Series APF and shunt APF, active power filters, connected back-to-back on the dc side, sharing a common DC capacitor. The series component of the UPQC is responsible for mitigation of the supply side disturbances: voltage sags/swells, flicker, voltage unbalance and harmonics. It inserts voltages so as to maintain the load voltages at a desired level; balanced and distortion free. The shunt component is responsible for mitigating the current quality problems caused by the consumer: poor power factor, load harmonic currents, load unbalance etc. It injects currents in the ac system such that the source currents become balanced sinusoids and in phase with the source voltages.The overall function of UPQC mainly depends on the series and shunt APF controller.

A. Block Diagram of UPQC

The system configuration of a single-phase UPQC is shown in figure given below.

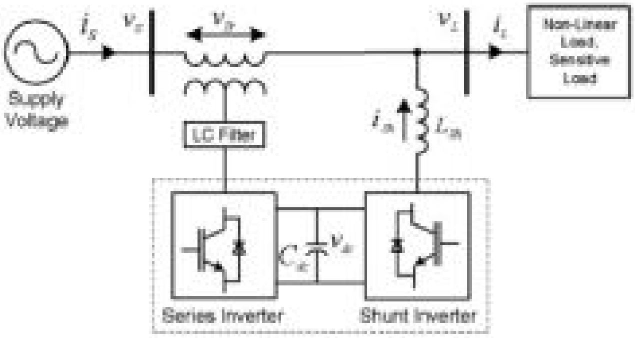

Fig.1 Block Diagram of UPQC.

UPQC consists of two IGBT based VSC, one shunt and one series cascaded by a common DC bus. The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers. The key components of this system are as follows.

1) Two inverters —one connected across the load which acts as a shunt APF and other connected in series with the line as that of series APF.

2) Shunt coupling inductor L is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape.

3) A common dc link that can be formed by using a capacitor or an inductor.

4) An LC filter that serves as a passive low-pass filter and helps to eliminate high-frequency switching ripples on generated inverter output voltage.

5) Series injection transformer that is used to connect the series inverter in the network. A suitable turn ratio is often considered to reduce the voltage and current rating of series inverter.

6) The integrated controller of the series and shunt APF of the UPQC to provide the compensating voltage reference Vc and compensating current reference Ic.

III. SYSTEM OVERVIEW

The designed system is depicted in Fig.2. The simulated grid contains a power source, which was simulated using a three phase programmable power source in Simulink, a pure resistive load and the hybrid system consisting of the UPQC+SMES. The series active filter that builds the UPQC is placed close to the power source and the shunt filter is placed close to the load. Although it is possible to choose a reverse configuration (shunt filter close to the source and series filter close to the load) this arrangement was chosen because it allows a better controllability of the DC bus voltage. This is a fundamental characteristic in this hybrid system because the SMES is connected to this DC bus.

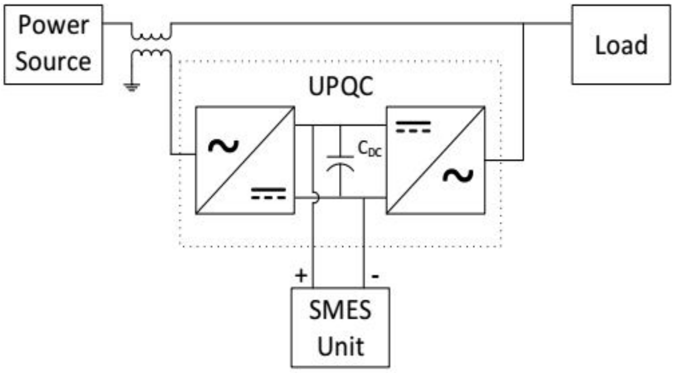

Fig.2 Implemented system.

A.UPQC

The UPQC is the main component of the designed system. Fig.3 shows a schematic of the implemented active power filter. The UPQC flexibility allows a full control of voltage and current. The series power active filter is responsible for voltage control and the shunt filter for current control. This control is possible by measuring the different values of voltages and currents in the grid and comparing them to reference values. The two filters are controlled using PWM generators and follow two different control strategies: the reference signal for the PWM generator of the series filter follows a “feed forward” control method, comparing the voltage of the filter to a well-defined reference value; on the other hand, the reference signal for the PWM generator of the shunt filter is obtained following a Synchronous Reference Frame Method [5]. A major responsibility of the UPQC controller is to maintain the DC bus voltage always above a required level. On this particular case, the chosen value is 700 V, which is higher than the minimum voltage necessary to have full controllability of both active filters at all time. The minimum value in this case is 648V, calculated following the formulation presented. The capacitor used in the DC bus has a value of 50 μF.

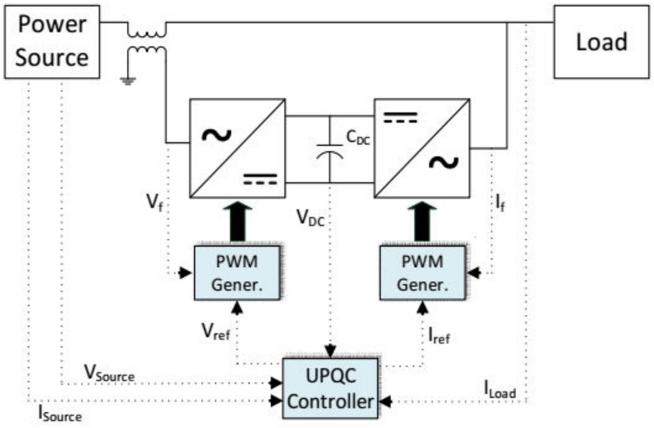

Fig.3 Implemented UPQC

B.SMES

An SMES is a very complex system, composed by three main components: a superconducting (SC) coil (placed inside a cryostat) where energy is stored; a Power Converter System (PCS), which is a power electronics bidirectional converter, responsible for the exchange of energy with the grid to which the SMES is connected, and a Control System (CS) responsible for controlling all energy exchanges with the grid and also for over viewing and protecting the conditions of the SC coil. Fig.4 depicts a typical configuration of the systems

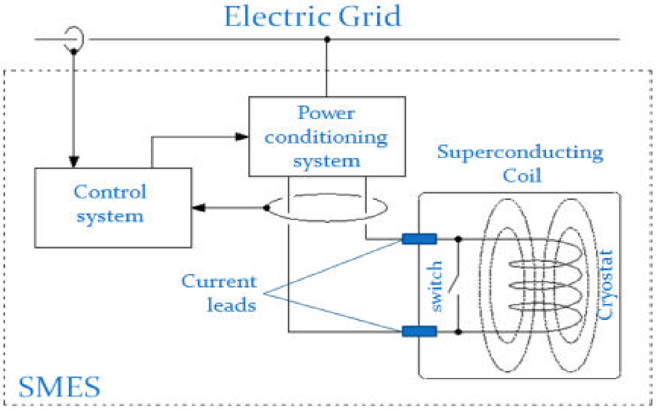

Fig.4 SMES system constitution

In this particular case, because it is a simulation work and because the SMES is connected to a DC bus, several simplifications are possible. The PCS becomes simpler than the used one when the SMES is connected to an AC grid. In this case, it is necessary to use only a DC/DC converter. The typical choice is a chopper converter, due to its simplicity. The control strategy used in the PCS also becomes simpler due to this fact, which will also decrease the complexity of the CS. Other simulations are performed on the controller of the SMES: all variables related to the cryogenic system and protection of the SC coil is not considered. However, since the hybrid system is supposed to be able to overcome voltage swells, it is necessary to add a resistor in parallel with the SC coil, so that the excess energy (in case of a voltage swell) can be dissipated. This dissipation of energy will only occur if the SMES is already fully charged. The model used for simulation of the SMES is represented in Fig.5. To simulate the chopper two IGBTs (S_1 and S_2) were used.

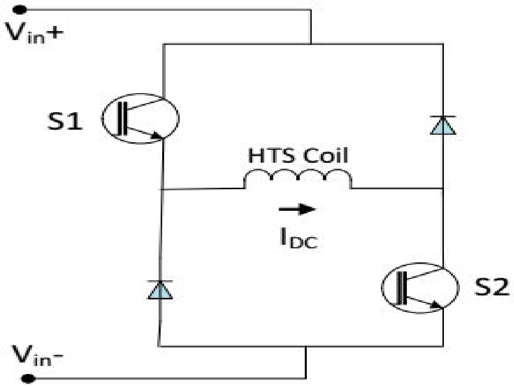

Fig.5 SMES model

The control of these two switches allows the SMES to work in three different modes:

- S1 and S2 closed – Charging Mode: the coil is charging;

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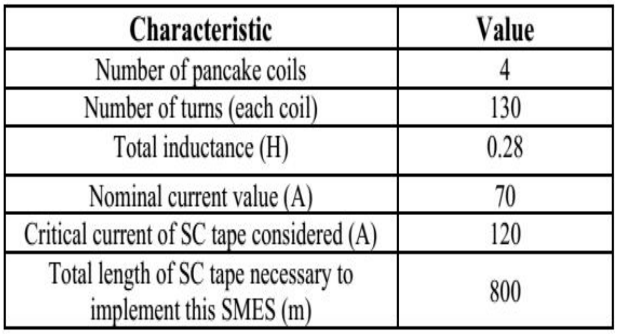
- S1 S2 closed – Discharging Mode: the coil is discharging, due to the occurrence of some fault in the grid;
- S1 open and S2 closed – Persistent Mode: the coil is already full charged and its nominal current value is kept using this mode.

When the SMES is operating alone, the charging process is straightforward. The energy can be extracted from the DC link without any special care. However, in this particular case, since the SMES is connected to the DC bus of an UPQC, it's the charging process must take into account the fact that the DC voltage cannot decrease below a certain level. Thus, it is only possible to charge the SMES when the DC voltage is above 700 V (the chosen value for the DC bus voltage). The controller of the SMES (which controls the IBGTs S1 and S2) must consider this aspect.The main characteristics from the SMES unit simulated in this work are presented in table I such characteristics were obtained following the method presented. The implemented model also considers a resistor (with 0.1 Ω) in series with the coil, to simulate the existence of connectors in the superconducting tape and a capacitor (with 1nF) in parallel, to simulate capacitance between the single pancake coils.

TABLE I

Characteristics Of The Simulated SMES Unit.



Characteristic	Value
Number of pancake coils	4
Number of turns (each coil)	130
Total inductance (H)	0.28
Nominal current value (A)	70
Critical current of SC tape considered (A)	120
Total length of SC tape necessary to implement this SMES (m)	800

In an UPQC operating alone, in the same conditions as in this case, i.e., the same DC voltage (700 V) and the same capacitor in the DC bus (50 µF), the stored energy is 12.25 J. This is a small value, which strongly limits the range of applications of such system, namely when used for voltage sags compensation. In this case, with an SMES with these characteristics connected to the DC link of the UPQC, the stored energy increases to 698.25 J. This represents an increase of 5700% in stored energy, which greatly expands the range of application of the hybrid system, when comparing to the UPQC alone.

C.FAULT DETECTION

To be able to overcome faults, it is first necessary to correctly and rapidly identify those events in the grid. Voltage sags and swells are detected following a method presented. Briefly, this method detects a voltage sag or swell by comparing the grid voltage value with a reference value. This reference value has the same phase and amplitude as the nominal voltage of the grid, which is very convenient because this is also used as a reference for the series active power filter.

IV. SUPERCAPACITOR

A super capacitor (SC) (sometimes ultra capacitor, formerly electric double-layer capacitor (EDLC)) is a high-capacity electrochemical capacitor with capacitance values much higher than other capacitors (but lower voltage limits) that bridge the gap between electrolytic capacitors and rechargeable batteries. They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable. They are however 10 times larger than conventional batteries for a given charge.Super capacitors are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage or burst-mode power delivery. Smaller units are used as memory backup for static random-access memory (SRAM). Super capacitors do not use the conventional solid dielectric of ordinary capacitors. They use electrostatic double-layer capacitance or electrochemical pseudo capacitance or a combination of both instead:

- Electrostatic double-layer capacitor use carbon electrodes or derivatives with much higher electrostatic double-layer capacitance than electrochemical pseudo capacitance, achieving separation of charge in a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte.
- The separation of charge is of the order of a few angstroms (0.3 0.8 nm), much smaller than in a conventional capacitor.
- Electrochemical pseudo capacitors use metal oxide or conducting polymer electrodes with a high amount of electrochemical pseudo capacitance. Pseudo capacitance is achieved by Faradic electron charge transfer with redo, intercalation or electro sorption.
- Hybrid capacitors, such as the lithium-ion capacitor, use electrodes with differing characteristics: one exhibiting mostly electrostatic capacitance and the other mostly electrochemical capacitance.

V. MATLAB/SIMULATIN RESULTS

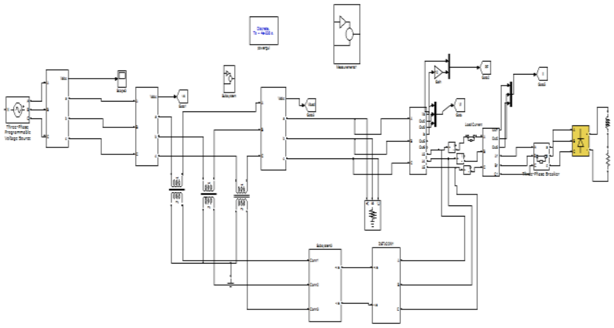


Fig.6 Simulation model of superconducting magnetic energy system of UPQC

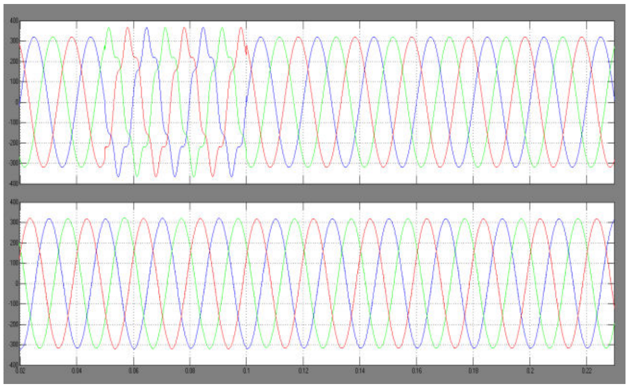


Fig.7 Harmonic distortion compensation: source (above) and load (below) voltages

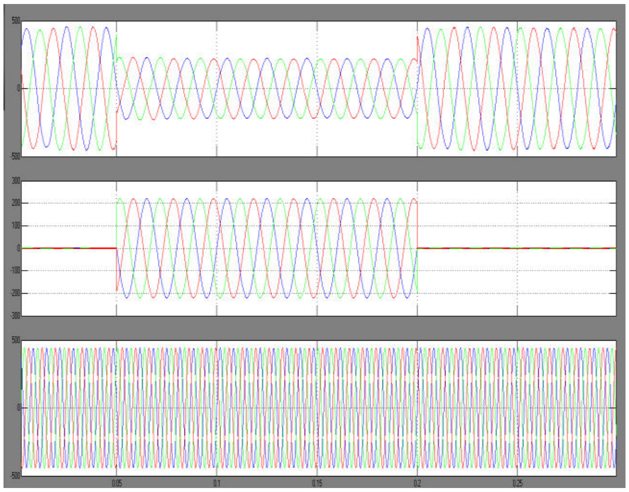


Fig.8 Voltage sag elimination: source (above) and load (below) voltages during the fault.

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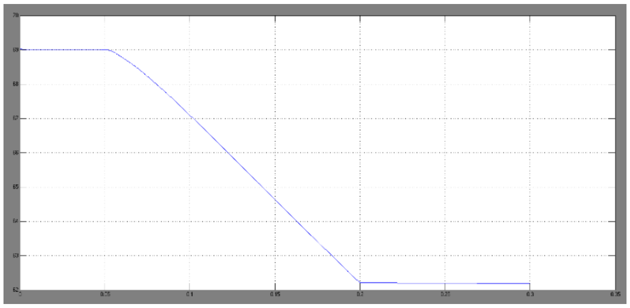

Fig.9 Current in the SMES during a three phase voltage sag.

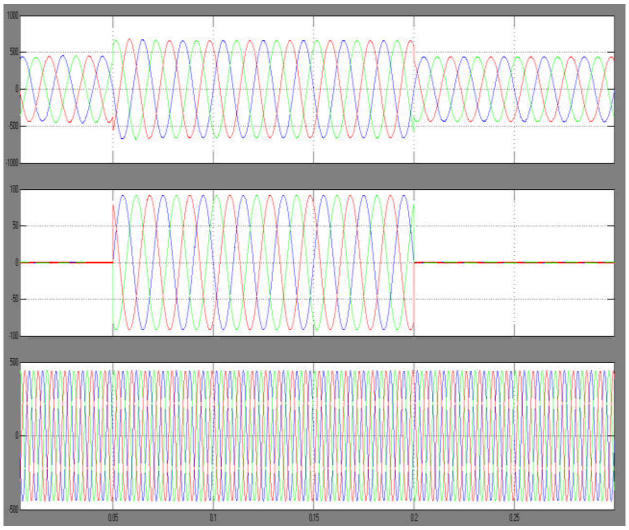

Fig.10 Voltage swell elimination: source (above) and load (below) voltages during the fault

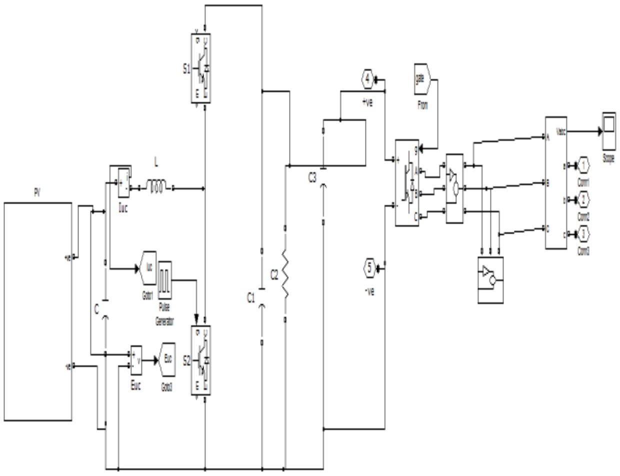

Fig.11 Simulation model of superconducting magnetic energy system of UPQC with super capacitor

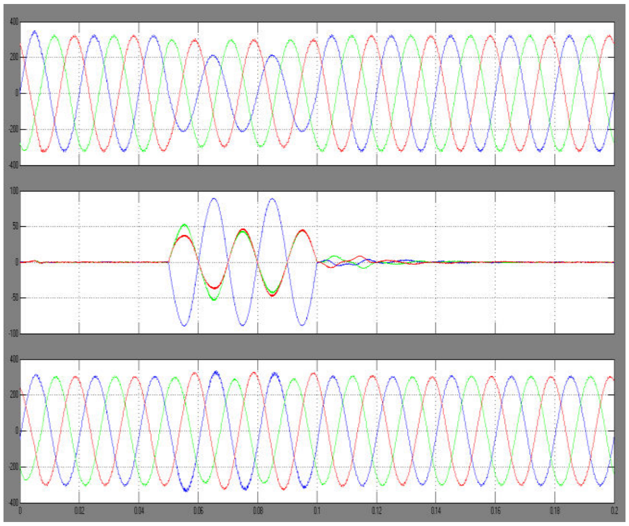

Fig.12 Harmonic distortion compensation: source (above) and load (below) voltages in super capacitor used

VI. CONCLUSION

The paper describes the analysis comparative results of a super-capacitor based unified power quality conditioner. Out of the custom power devices UPQC is the most effective device for mitigating the power quality problems. The performance of the proposed system consists of a DC/DC converter and super-capacitors connected through DC line. The proposed system can compensated voltage sag and swells with improved power factor, voltage interruption and harmonics. The proposed UPQC has the ultimate capability of improving the power quality at the installation point in the distribution system.

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