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Design of PFC Zeta Converter Fed Sensor Less PMSM Drive Using Pi Controller

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ABSTRACT— In many pulse width modulated DC-DC converter topologies, the controllable switches are operated in switch mode where they are required to turn the entire load current on and off during each switching cycle. Under these conditions, the switches are subjected to high switching stresses and power losses. Recently there is an increased interest in the use of resonant type DC-DC converters due to the advantages of high frequency of operation, high efficiency, small size, light weight, reduced Electro Magnetic Interference (EMI) and low component stresses.A novel PFC (Power Factor Corrected) Converter using Zeta DC-DC converter feeding a PMSM drive using a single voltage sensor is proposed for variable speed applications. A single phase supply followed by an uncontrolled bridge rectifier and a Zeta DC-DC converter is used to control the voltage of a DC link capacitor which is lying between the Zeta converter and a VSI (Voltage Source Inverter). The voltage of a dc-link capacitor of zeta converter is controlled to achieve the speed control of PMSM Drive. The zeta converter is working as a front end converter operating in DICM (Discontinuous Inductor Current Mode) and thus using a voltage follower. A sensor less control of PMSM is used to eliminate the requirement of Hall Effect position sensors. Using MATLAB/ Simulink 7.13 environment the model can be simulated to achieve a wide range of speed control with high power factor.

KEYWORDS— Adjustable Speed drives, DC-DC Converter, PI Control, PMSM drive, Zeta Converter**.**

I. INTRODUCTION

Modern electronic systems require high quality,[7] small, lightweight, reliable, and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient. They are limited to output voltages smaller than the input voltage. Also, their power density is low because they require low-frequency (50 or 60 Hz) line transformers and filters. Linear regulators can, however, provide a very high quality output voltage. Their main area of application is at low power levels as low drop-out voltage (LDO)regulators. Electronic devices in linear regulators operate in their active (linear) modes. At higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in *on* and *off* states. Since there is a small power loss in those states (low voltage across a switch in the *on* state, zero current through a switch in the *off* state), switchingregulators can achieve high energy conversion efficiencies. Modern power electronic switches can operate at high frequencies. The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors. In addition, dynamic characteristics of converters improve with increasing operating frequencies.

The bandwidth of a control loop is usually determined by the corner frequency of the output filter. Therefore, high operating frequencies allow for achieving a faster dynamic response to rapid changes in the load current and/or the input voltage. High-frequency electronic power processors are used in dc–dc power conversion.

II. PROPOSED SPEED CONTROL SCHEME OF SENSORLESS PMSM DRIVE

The proposed scheme for the Sensor less PMSM drive fed by a Zeta based PFC converter operating in DICM mode is shown in Fig.2.1.The front end Zeta DC-DC converter maintains the DC link voltage to a set reference value. Switch of the Zeta converter is to be operated at high switching frequency for effective control and small size of components like inductors. A sensor less approach[12]is used to detect the rotor position for electronic commutation.A high frequency MOSFET of suitable rating is used in the front end converter for its high frequencyoperation whereas an IGBT's (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation.

The proposed scheme maintains high power factor and low THD[10] of the AC source current while controlling rotor speed equal to the set reference speed. A voltage follower approach is used for the control of Zeta DC-DC converter operating in DICM.

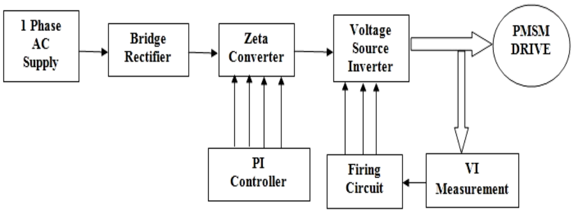

Fig.2.1. Proposed system block diagram

The DC link voltage is controlled by a single voltage sensor. V_{dc} (sensed DC link voltage) is compared with V_{dc}* (reference voltage) to generate an errorsignal which is the difference of V_{dc}* and V_{dc}. The error signal is given to a PI (Proportional Integral) controller to give a controlled output. Finally, the controlled output is compared with the high frequency saw tooth signal to generate PWM (Pulse Width Modulation) pulse for the MOSFET of the Zeta converter.

III. PRINCIPLE OF OPERATION OF PROPOSED ZETA CONVERTER

Vast majority of power converters used nowadays employ front-end diode bridge rectifiers. Such rectifiers draw pulsating currents which leave behind a great amount of harmonics, and considerably low power factor. For a single converter of this type used with a single-phase load such as in consumer electronic equipment, the problems may not seem serious. However, a great number of those equipment's in parallel connection at a point of common coupling (PCC) to draw power simultaneously introduce some serious effects concerning reactive power and harmonic. The situations are quite common in offices and industries.

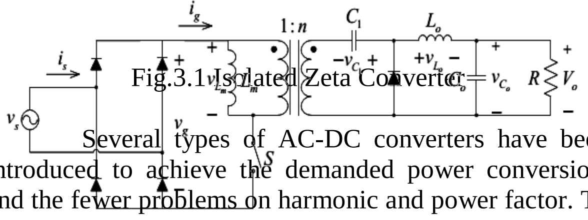

Fig.3.1 Isolated Zeta Converter

Several types of AC-DC converters have been introduced to achieve the demanded power conversion, and the fewer problems on harmonic and power factor. To name a few, these include the Cuk converter, [11]theSEPIC converter, the combined boost with double winding fly back converter, and the zeta converter. Among those, the zeta converter, which is originally the buck-boost type, can be regarded as a fly back type when an isolated transformer is incorporated. An isolated zeta converter has some advantages including safety at the output side, and flexibility for output adjustment.

Fig.3.1 depicts the circuit diagrams of the isolated zeta converter such that its operation principle in the CCM could be readily explained. Fig.3.2 represents the 1st region of operation in which the switch S is "on", and the diode D is "off". This region takes the time from 0 to d_1T_s seconds.

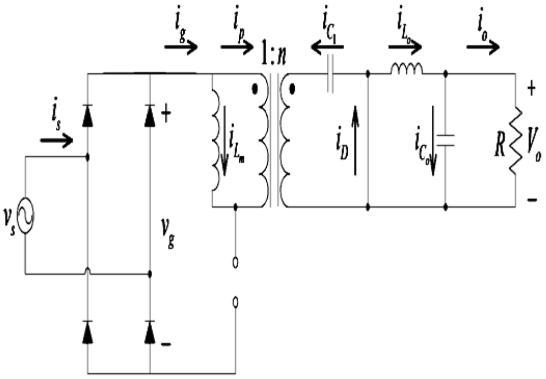

Fig.3.2 Ist Region of operation

The inductor L_m stores the energy received from the rectifier. The capacitor C_1 supplies energy to the load (R) via the inductor L_o, and the capacitor C_o. the currents through the inductors L_m and L_o increase linearly, while no current flows through the diode.

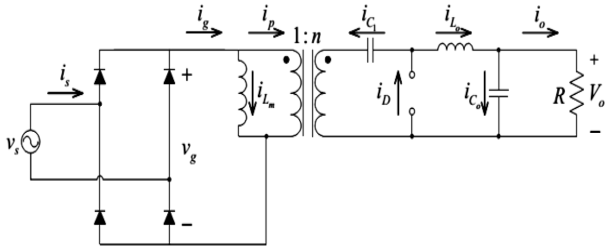

Fig.3.3 2nd Region of operation

Fig.3.3 represents the 2nd operation region in which the switch S is "off", and the diode D is "on". This region begins at the time d_1T_s seconds, and ends by d_2T_s seconds. The diode D is forward biased due to the voltage across the inductor L_m has reversed polarity, while the currents i_{Lm} and i_{Lo} decrease linearly. The stored energy in the inductor L_m is transferred to the capacitor C_1. The load R receives energy from the inductor L_o. Hence, the current $i_D = i_{C1} + i_{Lo}$.

IV. STATE SPACE AVERAGED MODEL OF PROPOSED ZETA CONVERTER

Considering the operation of the converter during the on- and off-time intervals denoted ast_{on} or d_1T_s, and t_{off} or

$(1\text{-}d_1)$ $T_s$respectively, the state equations in on switching cycle can be written as

$$\dot{x} = A_s\,x + B_s\,u \qquad y = C_s x \qquad (1)$$

Where,

$$A_s = [A_1 d_1 + A_2\,(1 - d_1)] \qquad (2)$$

$$B_s = [B_1 d_1 + B_2\,(1 - d_1)] \qquad (3)$$

$$C_s = [C_1 d_1 + C_2\,(1 - d_1)] \qquad (4)$$

Linearization can be made to the above equations by considering small-signal perturbations such that $x = X + \tilde{x}$,$y = Y + \tilde{y}$, $d_1 = D + \tilde{x}$, $u = U + \tilde{u}$where $X >> \tilde{x}$, $Y >> \tilde{y}$, $U >> \tilde{u}$, $D_1 >> \widetilde{D_1}$be substituted into Eq. (1). Under the steady-state condition of the state variables, the following equationscan be written as,

$$X = A_{av}X + B_{av}\,U = 0;\ Y = C_{av}X \qquad (5)$$

&

$$A_{av}\tilde{x} + [(A_1+A_2)\,X + (B_1+B_2)\,U]\tilde{d} + B_{av}\tilde{u} \qquad (6)$$

$$\tilde{y} + C_{av}\tilde{x} + [(C_1\text{-}C_2)\,X]\tilde{d} \qquad (7)$$

Where,

$$A_{av} = A_1 D_1 + A_2\,(1 - D_1) \qquad (8)$$

$$B_{av} = B_1 D_1 + B_2\,(1 - D_1) \qquad (9)$$

$$C_{av} = C_1 D_1 + C_2\,(1 - D_1) \qquad (10)$$

From Eq. (2)

$$X = -A_{av}{}^{-1}\,B_{av}\,U; \frac{Y}{U} = -C_{av}\,A_{av}{}^{-1}B_{av} \qquad (11)$$

Under small-signal assumption, taking the Laplace transform to Eq.(4) results in

$$\dot{x} = [sI - A_{av}]^{-1}[\,B_{av}\widetilde{V_g}(s) + [(A_1 - A_2)\,X + (B_1 - B_2)\,V_g]\,\widetilde{d_1}(s)] \qquad (12)$$

$$\tilde{y}(s) + C_{av}\tilde{x}(s) + [(C_1 - C_2)X]\tilde{d}\,(s) \qquad (13)$$

Finally, the transfer functions can be obtained:

forn $\widetilde{V_g} = 0$

$$\frac{\tilde{y}\,(s)}{\widetilde{d_1}(s)} = C_{av}\,[sI - A_{av}]^{-1}\big[(A_1 - A_2)\,X + (B_1 - B_2)\,V_g + C1{-}C2X \qquad (14)$$

And for $\widetilde{d_1} = 0$

$$\frac{\tilde{y}\,(s)}{\widetilde{V_g}(s)} = C_{av}\,[sI - A_{av}]^{-1}C_{av} \qquad (15)$$

V MATHEMATICAL MODEL OF THREE PHASE VOLTAGE SOURCE INVERTER AND PMSM

1.Mathematical Model of Three Phase VSI

The PMSM armature winding is to be supplied from a 3 phase VSI whose power electronics devices (switches) would be switched according to the rotor position information for achieving VectorControl. The power circuit of a typical 3 phase, 2 level VSI [7] catering to a 3 phase armature winding of a 3 phase AC motor is shown in Fig.5.2 The inverter devices marked as T_1 , T_2 , T_3 , T_4 , T_5 , T_6 are to be switched to achieve Vector-Control as per a Sinusoidal Pulse Width Modulation (SPWM) strategy.

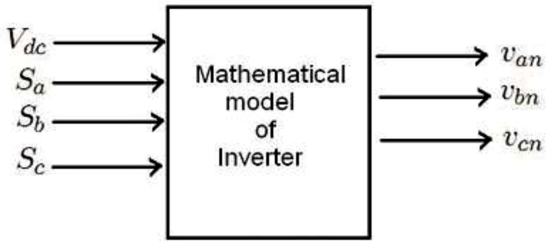

Fig5.1 Mathematical model of the 3 phase voltage source inverter

The mathematical model of the 3 phase VSI, as shown in Fig 5.1 as a block, should have the DC link voltage (V_{dc}), the 3 switching functions (Boolean variables) S_a , S_b and S_c as input variables and should have the 3 phase voltages v_{an} , v_{bn} and v_{cn} as output variables. The output variables of the inverter will form as the input phase voltages to be fed to the PMSM armature winding (Star connected).

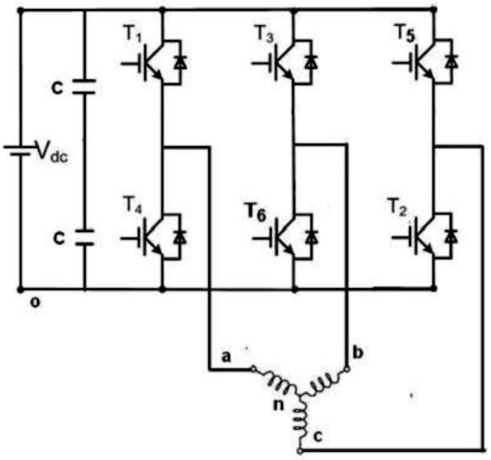

Fig 5.2 Three-Phase Sine-PWM Inverter with three phase load

Voltages V_{ao}, V_{bo} and V_{co} may be represented in terms of the switching functions as

$$V_{ao}= V_{dc}S_a \qquad (16)$$

$$V_{ao}= V_{dc}S_a$$

(17)

$$V_{ao}= V_{dc}S_a$$

(18)

Where, V_{ao} is the voltage of point `a' with respect to -ve DC link bus. Similar nomenclature is also applicable for other two phases. [7]The 3 phase voltage impressed on the star connected armature winding of PMSM (these are output voltage of the inverter) can be represent as,

$$V_{an} = V_{ao} - V_{no} \qquad (19)$$

$$V_{bn} = V_{bo} - V_{no} \qquad (20)$$

$$V_{cn} = V_{co} - V_{no} \qquad (21)$$

where V_{no} = The voltage of the neutral point `n' with respect to the point `o' of the DC bus. $V_{an} + V_{bn} + V_{cn} = V_{ao} + V_{bo} + V_{co} - 3V_{no}$ assuming that the machine being balanced$V_{an} + V_{bn} + V_{cn} = 0$. Hence inverter phase voltages can be expressed as,

$$V_{an} = V_{ao} - \frac{V_{ao} + V_{bo} + V_{co}}{3}$$

$$= \frac{2V_{ao} - V_{bo} - V_{co}}{3}$$

$$V_{an} = \frac{2S_a-(S_b+S_C)}{3} \qquad (22)$$

Similarly,

$$V_{bn} = \frac{2S_b-(S_c+S_a)}{3} \qquad (23)$$

$$V_{cn} = \frac{2S_c-(S_a+S_a)}{3} \qquad (24)$$

II.Mathematical Model of PMSM:

The stator of the PMSM and the wound rotor synchronous motor (SM) with armature in stator are similar. In addition there is no difference between the backEMF produced by a permanent magnet in a PMSM [3]and that produced by an excited coil in a SM. Hence the mathematicalmodel of a PMSM is similar to that ofthe wound rotor SM. The rotor frame of reference is chosen because the PMSM three phase armature winding is fed from a 3 phase voltage source inverter (VSI), whichis switched in synchronism with the rotor position information of the PMSM.

Hence the frequency of the voltage or current in the PMSM armature winding atall instants is same as the electrical speed of the machine; electrical speed beingrelated to mechanical speed through the no. of poles of the machine. The following assumptions are madewhich deriving the D-Q model of the PMSM in rotor reference frame.[3]

1. Saturation is neglected.
2. The back EMF is sinusoidal.
3. Eddy currents and hysteresis losses are negligible.

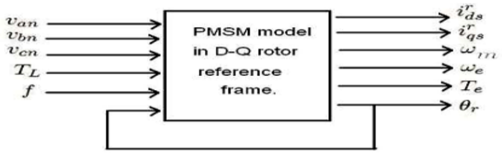

Fig5.3 PMSM model block in D-Q reference frame, denoting input andoutput variables

The mathematical model is presented as a block in Fig. 5.3, where the three armature phase voltages (machine assumed to be star connected),[3] load torque parameters are input variables to the motor; and the armature current, electromagnetic torque, electrical speed, mechanical speed and rotor position are considered output variables. The rotor position is fed back as an input variable to the motor model.

VI. SIMULATION RESULTS & DISCUSSION OF A PROPOSED ZETA CONVERTER

A PMSM system of 2300 rpm, 300 V, 14.3 N-m is taken for proposed speed control scheme using Zeta Converter. The proposed zeta converter has designed with the voltage output range from 0 to 500 V. A PI controller has used for voltage regulation and Speed Controller with proportionality and integral constant values of 0.013, 16.61 and 139.7290, 54.6363 respectively. The Proposed Scheme has implemented using MATLAB/SIMULINK shown in Fig 6.1& Fig 6.2.

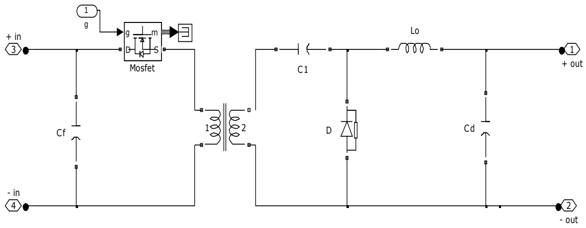

Fig.6.1. SIMULINK model of proposed zeta converter

II .Simulation Results

Fig. 6.3 shows the simulated speed response of PMSM with the set value of 2200 rpm and torque T= 5 N-m.The speed response obtained as the settling time less than 0.1s

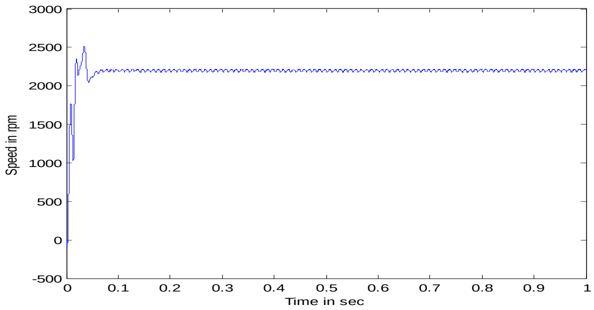

Fig 6.3 Simulated Speed response of PMSM with set value of 2200 rpm, T=5 N-m

The simulated torque response of zeta converter fed PMSM with the set value of 2200 rpm and torque value can be obtained as T= 5 N-m can be shown in Fig.6.4The simulated rotor current response of zeta converter fed PMSM with the set value of 2200 rpm with T= 5 N-m can be shown in Fig.6.5

The simulated output voltage & inverter output voltage response of zeta converter fed PMSM with the set value of 2200 rpm with T= 5 N-m can be shown in Fig.6.6 & 6.7 respectively.

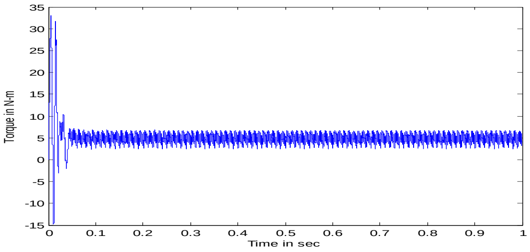

Fig 6.4 Simulated Torque response of PMSM with set value of 2200 rpm, T=5 N-m

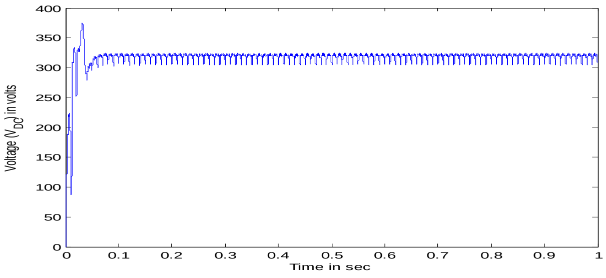

Fig 6.6 Simulated output voltage response of Zeta converter with set value of 2200 rpm, T=5 N-m.

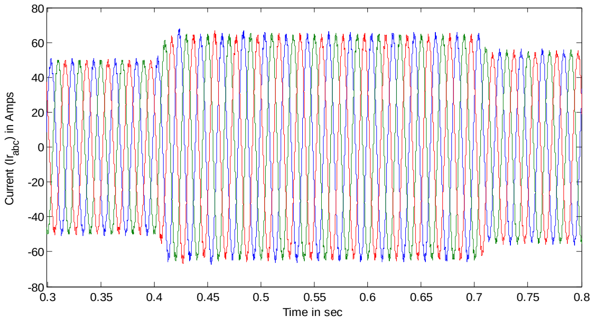

Fig 6.5 Simulated Rotor current of PMSM with set value of 2200 rpm, T=5 N-m

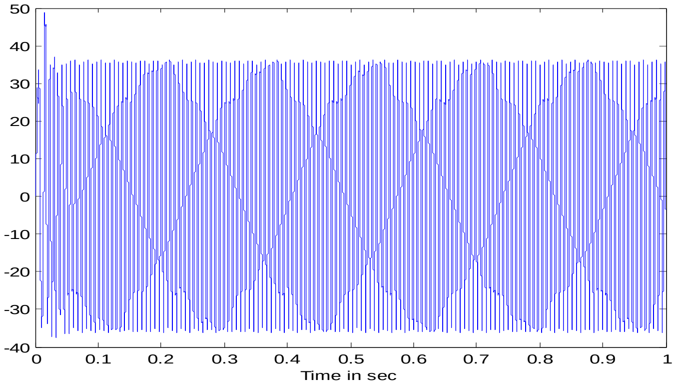

Fig 6.7 Simulated inverter voltage response with set value of 2200 rpm, T=5 N-m

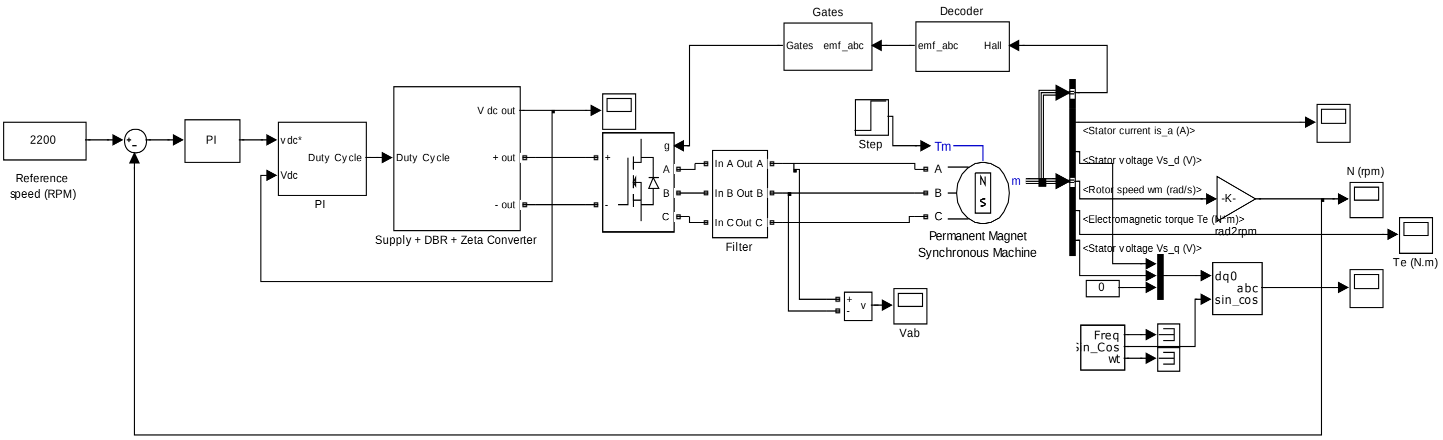

Fig 6.2 MATLAB/Simulink model for PMSM Drive using Zeta Converter

VII.CONCLUSION

A simple control using a voltage follower approach has been used for voltage control and power factor correction of a PFC Zeta converter fed PMSM motor drive. A single stage PFC converter system has been designed and validated for the speed control with improved power quality at the AC mains for a wide range of speed. The performance of the proposed drive system has also been evaluated for varying input AC voltages and found satisfactory. The power quality indices for the speed control and supply voltage variation have been obtained within the limits by International power quality standard IEC 61000-3-2.The proposed drive system can be used in various adjustable speed drives for many low power applications.

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