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POWER QUALITY IMPROVEMENT WITH FUZZY CONTROL OF PMSG BASED DG SET FEEDING THREE-PHASE LOADS

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Abstract- The paper describes an advanced approach to power quality enhancement with PMSG (Permanent Magnet Synchronous Generator) based DG (Diesel Generator) set feeding three-phase loads using STATCOM (Static Compensator) with fuzzy controller is proposed in this paper. Here we are using the fuzzy controller compared to other controllers i.e. The fuzzy controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. A 3-leg VSC (Voltage Source Converter) with a capacitor on the DC link is used as STATCOM. The reference source currents for the system are estimated using an Adaline based control algorithm. A PWM (Pulse Width Modulation) current controller is using for generation of gating pulses of IGBTs (Insulated Gate Bipolar Transistors) of three leg VSC of the STATCOM. In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. The performance of the system is analyzed on various types of loads under steady state and dynamic conditions. The DG set is run at constant speed so that the frequency of supply remains constant irrespective of loading condition. By using the simulation results we can analyze the proposed method.

Keywords- STATCOM, Fuzzy logic controller, VSC, IGBTs, PMSG, PWM, DG Set, Power Quality.

INTRODUCTION

Power quality defines the fitness of electric power to consumer devices i.e. Synchronization of the voltage frequency and phase allow electrical system to function without any significant loss in performance. In distribution system the distribution networks and sensitive industrial loads are suffering from different type of outage and interruption which can lead to loss in production and other measurable and non measurable factor. PMSGs have gained popularity in recent years because of their potential use in WECS (Wind Energy Conversion Systems) [1-4]. The main challenges in PMSG are voltage and frequency control under varying load conditions. These challenges can be easily addressed with advancement in power converters. PMSG is compact in size so these generators have potential applications in DG (Diesel Generator) set based isolated supply systems. The diesel generator sets are run at a constant speed with the diesel engine as a prime mover. There is no issue of frequency control in these supply systems. They have presented that the inverse saliency effect of PMSG helps in improvement of voltage regulation of the generator. The voltage of PMSG based DG set in isolated supply systems can be controlled using STATCOM(Static Compensator). STATCOM is widely used in grid connected and isolated supply systems such for voltage and frequency control [6]. In addition, it can be used for load balancing, harmonics elimination, load compensation and reactive power compensation. In the proposed system with PMSG driven by diesel engine, STATCOM is used for voltage control of the PMSG. Many control algorithms are available for generation of reference source currents.

II. SYSTEM CONFIGURATION

The proposed system consisting of a PMSG based DG set, a three leg VSC, and linear/nonlinear loads, is shown in Fig. 1.

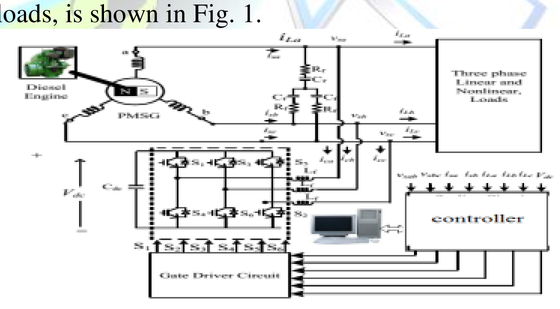

Fig. 1 Configuration of PMSG based DG set feeding three phase loads

A RC filter is used for filtering high frequency ripple from voltage at PCC (Point of Common Coupling). A 3-leg VSC is used a STATCOM. The VSC is connected to PCC through three interfacing inductors. The interfacing inductors connected between three legs of VSC and PCC are used to filter the high frequency ripples from current.

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III. CONTROL ALGORITHM

Fig.2 demonstrates an Adeline based control algorithm used in the proposed system for estimation of reference source currents.

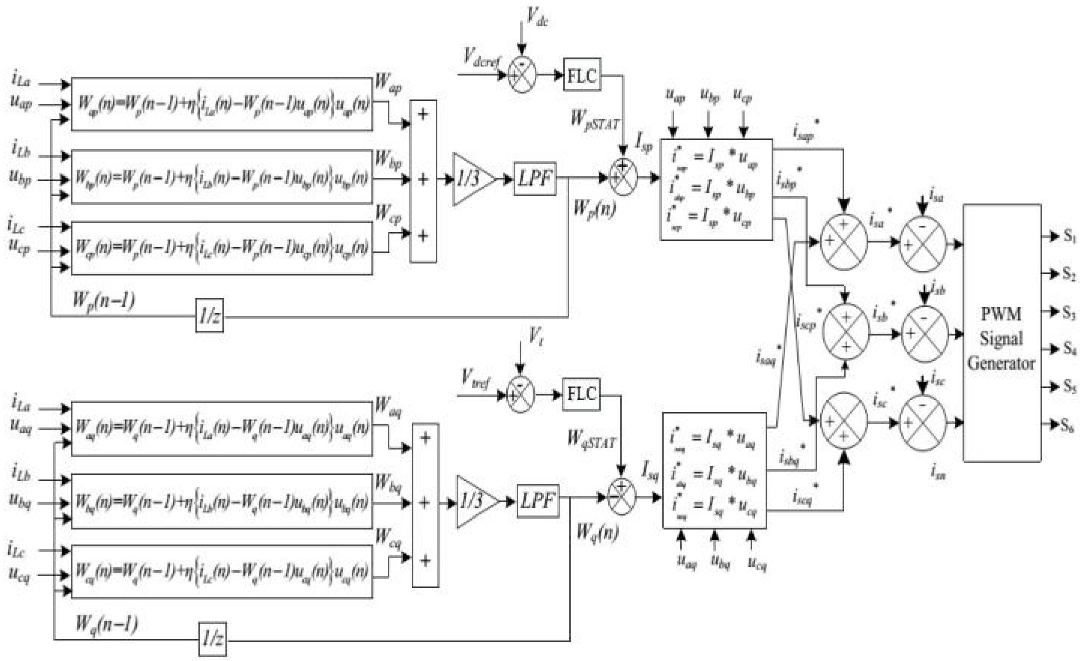

Fig.2 Adaline based control algorithm for PMSG Based DG set feeding three-phase loads

The Adaline based control algorithm estimates amplitude of fundamental components of active and reactive components of load currents. It uses a fixed step size which may have any value from 0.1 to 1 for fast convergence. In phase and quadrature phase unit templates are used for estimation of reference source currents. [7] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.

A. Extraction of Quadrature Phase and In-Phase Unit Templates

In-phase unit templates are extracted by dividing instantaneous phase-voltages by amplitude of phase voltages (Vt) as,

$$u_{ap} = \frac{v_{sa}}{V_t}, \quad u_{bp} = \frac{v_{sb}}{V_t}, u_{cp} = \frac{v_{sc}}{V_t}, \qquad (1)$$

where v, vsb and vsc are instantaneous phase-voltages which are obtained from sensed lined voltage obtained as [19].

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & 1 \\ -1 & 1 \\ -1 & -2 \end{bmatrix}\begin{bmatrix} v_{sab} \\ v_{sbc} \end{bmatrix} \qquad (2)$$

The amplitude of phase voltages is obtained from instantaneous phase voltages as [19],

$$V_t = \sqrt{\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)} \qquad (3)$$

The quadrature unit templates are extracted using in-phase unit templates as,

$$u_{aq} = \left(-u_{bp} + u_{cp}\right)/\sqrt{3} \qquad (4)$$

$$u_{bq} = \left(3u_{ap} + u_{bp} - u_{cp}\right)/2\sqrt{3} \qquad (5)$$

$$u_{cp} = \left(-3u_{ap} + u_{bp} - u_{cp}\right)/2\sqrt{3} \qquad (6)$$

B. Estimation of Active Power Component of Reference Source Current

The Adaline minimizes the error between actual load current and its estimated weight by optimizing the weights of active and reactive components of load currents. The weight vector for active component of load current of each phase is expressed as [22],

$$w_p(n) = w_p(n-1) + \mu^* \left\{ i_L(n) - \left\{ W_p(n) * u_p(n) \right\} \right\} * u_p(n) \qquad (7)$$

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where, μ is fixed step size having any value from 0.1 to 1. Here the step size in proposed system is taken to be 0.2.

For a three phase system, the weight of active component of load current is given as,

$$W_p(n) = \frac{W_{ap}(n)+W_{bp}(n)+W_{cp}(n)}{3} \quad (8)$$

where W ap(n), Wbp(n) and Wcp(n) are weights corresponding to active components of load currents in phase ‘a’, phase ‘b’ and phase ‘c’ respectively.

The final estimated weight of the amplitude of active power component of reference source current is given as,

$$W_{pT}(n) = W_{pSTAT}(n) + W_p(n)$$

The instantaneous active components of 3-phase reference source currents are obtained by multiplying weight vector of active power component and in-phase unit templates as under,

$$i_{sap}^*(n) = W_{pT}(n)^* u_{ap}(n) \quad (12)$$

$$i_{sbp}^*(n) = W_{pT}(n)^* u_{bp}(n) \quad (13)$$

$$i_{scp}^*(n) = W_{pT}(n)^* u_{cp}(n) \quad (14)$$

C. Estimation of Reactive Power Component of Reference Source Current

The weight vector for reactive power component of load current of each phase is given as,

$$W_q(n) = W_q(n-1) + \mu^* \left\{ i_L(n) - \{W_{qT}(n) * u_q(n)\} \right\} * u_q(n) \quad (15)$$

Final weight of reactive component of load current is given as,

$$W_q(n) = \frac{W_{aq}(n)+W_{bq}(n)+W_{cq}(n)}{3} \quad (16)$$

where W aq(n), Wbq(n) and Wcq(n) are weights corresponding to the reactive components of load currents in phase ‘a’, phase ‘b’ and phase ‘c’ respectively.

D. Estimation of Reference Source Currents

The instantaneous reference source currents are obtained by adding instantaneous active and reactive power components of reference source currents as under,

$$i_{sa}^* = i_{sap}^* + i_{saq}^*,$$

$$i_{sb}^* = i_{sbp}^* + i_{sbq}^*,$$

$$i_{sc}^* = i_{scp}^* + i_{scq}^*$$

The estimated reference source currents and sensed source currents are compared with each other and error is given to the PWM current controller to generate gating pulses for IGBTs (Insulated Gate Bipolar Transistors) of VSC of STATCOM.

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

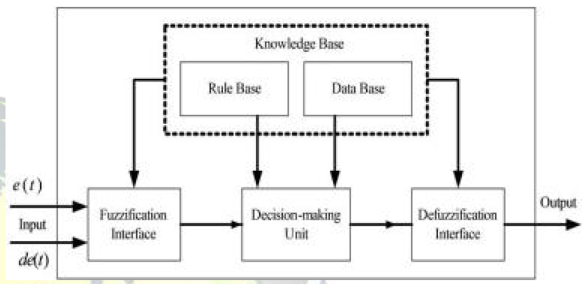

Fig.10.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani’s, ‘min’ operator. v. Defuzzification using the height method.

TABLE III: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The value of input error and change in error are normalized by an input scaling factor.In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular

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shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (23)$$

$$CE(k) = E(k) - E(k-1) \quad (24)$$

Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. **Defuzzification:** As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha E + (1-\alpha) * C] \quad (25)$$

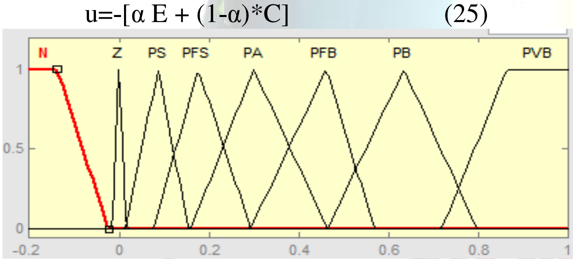


Fig 11 input error as membership functions

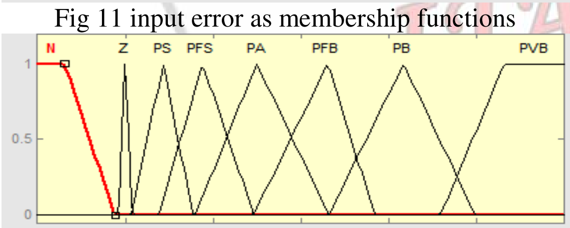


Fig 12 change as error membership functions

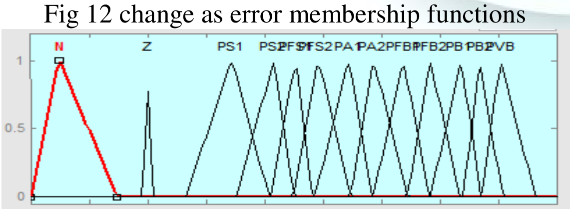


Fig.13 output variable Membership functions

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable.

V. RESULTS AND DISCUSSION

Performance of the system is analyzed under linear and nonlinear loads at steady state and transient conditions. Linear load is a simple RL type load. The nonlinear load is realized by using a three phase rectifier with a resistance on DC link.

Performance of DG System Under Linear Loads

The performance of the PMSG based DG set under linear load is demonstrated. The STATCOM supplies leading 2.37 kVAR to maintain terminal voltage at fixed level.

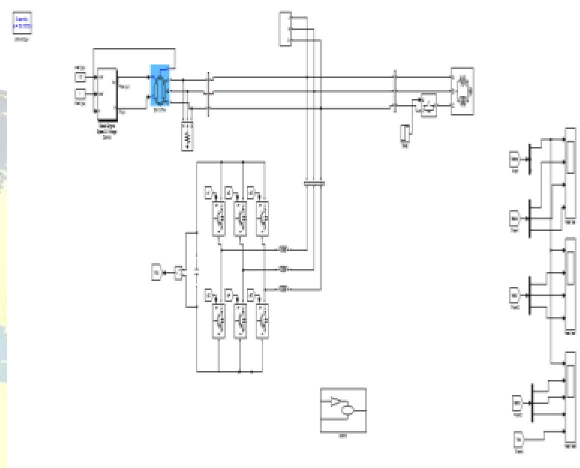
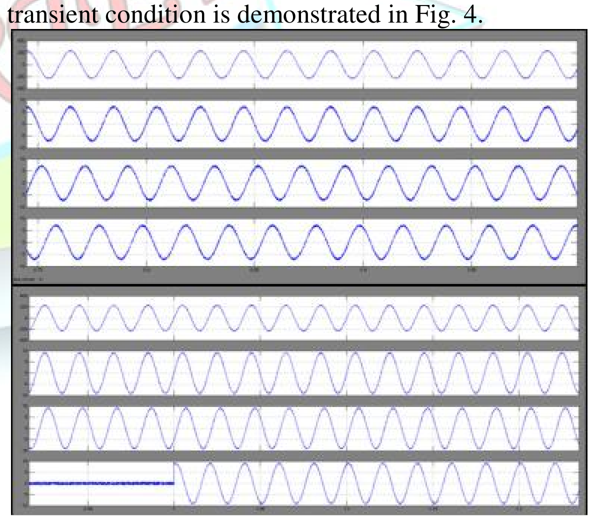


Fig.3 Block diagram of simulation

The dynamic performance of the system under the transient condition is demonstrated in Fig. 4.



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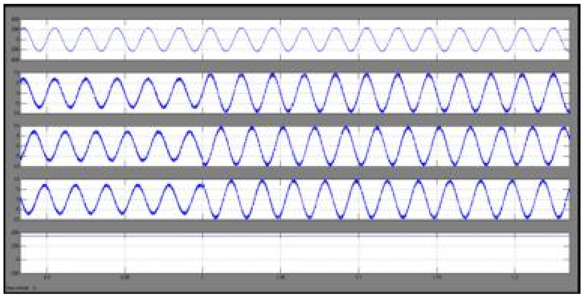
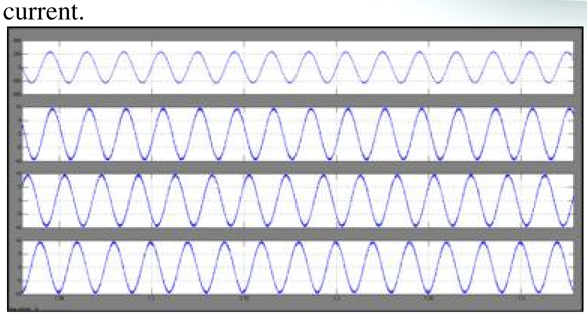


Fig. 4. Dynamic performance at linear loads (a) vsab, isa,isb and isc ,(b) vsab, iLa,iLb and iLc (c) Vdc, isa, iLa and iCa

The system is subjected to three phase load of 3.16 kW at displacement power factor of 0.90. Initially, the system is subjected to unbalanced load by removing the load from phase'c'. The dynamic performance of system is tested by changing the load from unbalanced to balanced by inserting the load in phase 'c'. It can be observed from these waveforms that system is able to overcome the transient within couple of cycles. It is also observed the DC link voltage has slight oscillatory under unbalanced condition and has under shoot during transient. The DC link capacitor supplies the energy stored to meet the additional load demand during the transient period.

A. Performance of DG System Under Nonlinear Loads

The performance of the system under nonlinear load is illustrated in Fig. 5. The system is subjected to a balanced nonlinear load of 2.99 kW. Figs.5(a)-(c) show the source voltages (vsab) and source currents (isa, isb, isc). Figs. 5(d)-(f) show the source voltage (vsab) and load currents (iLa,iLb,iLc). Figs. 5(g)-(i) show the source voltage (vsab) and STATCOM current ((iCa,iCb,iCc). Figs. 5(j)-(l) display the real and reactive powers of source, load and STATCOM respectively. Figs. 5(m)-(o) show the THDs of the source voltage, source current and load current.



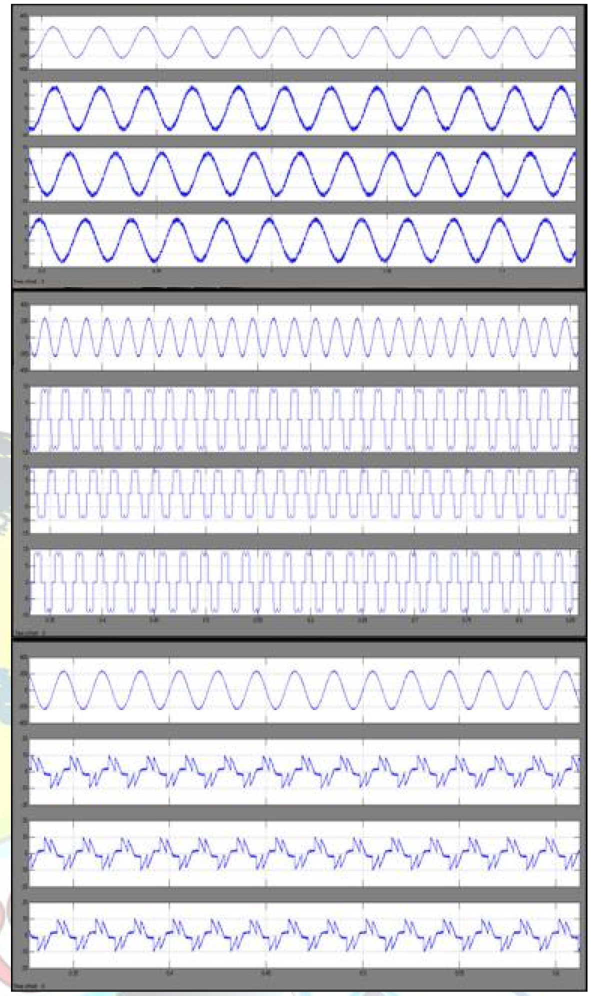


Fig. 5. Performance under balanced nonlinear loads (a) vsab and isa(b) vsab and isb(c) vsab and isc (d) vsab and iLa (e) vsab and iLb (f) vsab and iLc (g) vsab and iCa (h) vsab and iCb (i) vsab and iCc (j) Ps and Qs (k) PL and QL (l) PC and QC (m) THD of vsab (n) THD of isa(o) THD of iLa

It can be seen that the load currents are highly distorted with THD of 24.4 %. The STATCOM is able to eliminate majority of harmonics from the source currents. So the source current has THD of 3.9%. The STATCOM is able to supply enough reactive power for voltage regulation. The STATCOM supplies a reactive power of 2.33 kVAR with lagging power factor for a load of nonlinear load of 2.99 kW.

VI. CONCLUSIONS

The STATCOM has improved the power quality of the PMSG based DG set in terms voltage control, harmonics elimination and load balancing. Under linear loads, there has been negligible voltage variation (From 219.1 V to 220.9 V) and in case of nonlinear load, the voltage increases to 221 V. Thus, the STATCOM has been found capable to maintain the terminal voltage of DG set within 0.5% (220 1 V) under different linear and nonlinear loads. Under nonlinear loads, the load current of DG set is a quasi square with a THD of 24.4 %. The STATCOM has been found capable to eliminate these harmonics and thus the THD of source currents has been limited to 3.9 % and the THD of terminal voltage has been observed of the order of 1.8%. It has also been found that the STATCOM maintains balanced source currents when the load is highly unbalanced due to removal of load from phase 'c'.However, the speed control mechanism of prototype of the diesel engine is able to maintain the frequency of the supply almost at 50 Hz with small variation of ±0.2 %. Here we are using the fuzzy controller compared to other controllers i.e. The fuzzy controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. Therefore, the proposed PMSG based DG set along with STATCOM can be used for feeding linear and nonlinear balanced and unbalanced loads. The proposed PMSG based DG set has also inherent advantages of low maintenance, high efficiency and rugged construction over a conventional wound field synchronous generator based DG set.

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