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Performance Analysis of Fuzzy Logic Controller Based DVR for Power Quality Enhancement

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ABSTRACT

This paper presents a fuzzy logic controller (FLC)-based dynamic voltage restorer (DVR) to reduce power quality (PQ) issues in the distribution system (DS). The FLC-DVR injects voltage into the line to maintain voltage stability in the DS. The DVR is a Series FACTS device, which is connected in series with the system to improve power quality. The FLC is a novel control method to control the operation of a DVR. By using the FLC controller, the DVR responds very quickly to disturbances in the DS. The entire proposed system is designed and tested in the MATLAB/SIMULINK software. The updated simulation results show the FLC-DVR is more accurate compared to a conventional PI controller.

Keywords : Fuzzy Logic Controller (FLC), Dynamic Voltage Restorer (DVR), Power Quality (PQ), FACTS, Total Harmonic Distortion (THD), Voltage Source Inverter (VSI).

I. INTRODUCTION

Electrical energy is increasingly acknowledged as a basic necessity for consumers [1]. It is invisible, a commodity that is instantly available. Solar, solar thermal, wind, and other renewable energy sources all use renewable energy systems (RESs) to help to meet their primary energy needs. The intermittent nature of RESs, harmonics, and reactive power issues causes stability issues in the power system, which halts the performance of the power system [2, 3]. The Flexible AC Transmission Systems (FACTS) devices are widely used in distribution grids for reactive power compensation, voltage stability, and power quality [4,5]. FACT devices, however, also modify certain transmission and distribution system aspects [6].

This paper presents a study of power quality with the goal of determining the root causes of bad power quality and offering remedies for these power quality issues. Computers, laptops, relays, solid-state devices, variable speed drives, and optical devices are a few examples of what is referred to as sensitive equipment. These devices are sensitive to changes in input voltage brought on by interference from other system components.

The power system is separated into the following sections: generation, transmission, and distribution.

On the distribution side, additional transmission lines are used to feed the power systems to various loads. When variable power is given to the load, power quality is crucial to the power system.

Consequently, the weak power quality has an impact on residential and commercial clients with sensitive loads. Even though there are different types of loads on the distribution side, sensitive loads are more negatively impacted by low power quality than other loads.

Many applications, including hospital operating rooms, semiconductor systems in processing facilities, database systems, instruments to regulate air pollution in crowded places, precise and accurate equipment needed for data processing, and service providers, have an increasing demand for sensitive loads. These devices could malfunction due to dips in voltage or distorted voltages caused by the power supply, which would result in severe financial loss.

Therefore, electricity quality has an impact on the distribution side.

The power system establishes the electrical characteristics that ensure smooth operation of the system and fulfils its purpose. This article discusses voltage swell and distorted voltage with significant harmonic content. The occurrence of faults generates voltage sag, transient, swell, and high distorted voltage with harmonics and Total Harmonic Distortion (THD) when the load voltage is disrupted. Most delicate instruments are most susceptible to voltage sags and harmonics issues. As a result of voltage sag, a few issues might arise, including device burning, misfiring, and disturbances in motor torques. For power quality to be resolved properly, the harmonic is a crucial problem.

A voltage sag or voltage dip is a short-duration reduction in the voltage of an electric power distribution system [7]. The initiation of the load and remote fault clearance carried out by utility are the primary causes of sag. The current generated by the motor at start up is six times greater than the actual current. A significant quantity of reactive power is absorbed during the starting of the motor, which causes voltage sag to appear. Figure 1 shows the voltage sag.

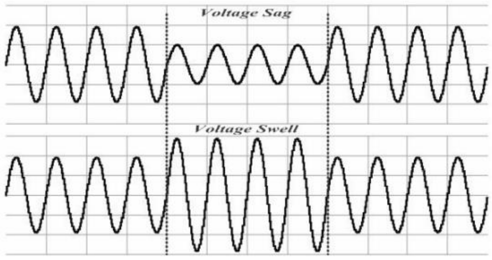


FIGURE 1. Voltage waveform with sag and swell [7]

Voltage swell is the increase in voltage value over its fundamental value, such as the change in voltage from 10% to 80% during a half-cycle to 1-minute period. Similar to this, it results in overvoltage when the voltage profile keeps rising. Voltage swell can be classified into three different categories: instantaneous, momentary, and temporary. Voltage swell can also be brought on by disrupted connections to big loads. Line to Ground Fault is the result of a loose connection (SLG). Voltage swells can lead to overheating, the damage of electrical equipment, and insulation collapse. The voltage swell in the voltage profile is seen in Figure 1. When fundamental frequency increases to three times, then a voltage issue known as harmonic distortion results. For instance, the fundamental frequency of 50 Hz changes to 150 Hz when multiplied by three. Figure 2 depicts the waveform with harmonic content. In power electronics, harmonics are produced by the switching process. Circuit breakers tripping, the overheating of neutral conductors, transformers, and other power distribution equipment, as well as the destruction of circuits are contributors to presence of harmonic [3, 8].

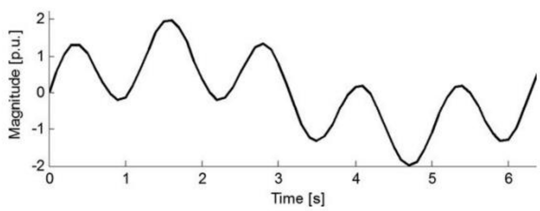


FIGURE 2. Waveform with harmonic content [7]

To address the above issue, the present work is proposed. The summary of this proposed work contributions:

- To lower the THD below 5% by addressing the issue of distorted voltage brought on by sags, swells, or harmonics.
- To access and examine the performance of the proposed model both with and without the usage of DVR in MATLAB/SIMULINK.
- To analyse the electrical system while adding the third and fifth harmonics to the input voltage profile.
- To compare the outcomes of the DVR-based system with and without the insertion of the 3rd and 5th harmonics.

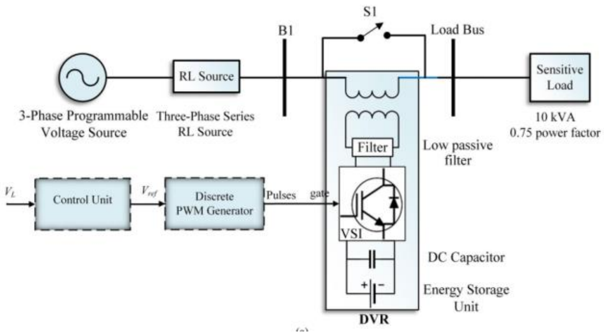
In this proposed work, novel fuzzy logic controller (FLC) is implemented to improve the performance of DVR and compare it to different conventional methods. By using an FLC-based DVR, the system voltage stability is improved and power oscillations were reduced. The FLC is a rule-based system. FLC is divided into three parts: Fuzzification, defuzzification, and rule base.

The remaining part of the paper is structured as follows: part II contains the system description. Section III illustrates the proposed method; Section IV presents and discusses the simulation results; and Section V concludes with a summary of the main conclusions of this work.

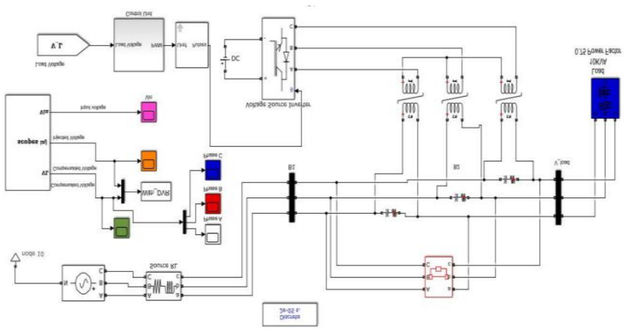
II. SYSTEM DESCRIPTION

The frequency of the provided voltage defines the quality of the power supply, which is a key sign of power quality. According to IEEE standards [22]–[24], the voltage sag is defined as a drop in the Root Mean Square (RMS) value of the voltage that can occur between 10 milliseconds and 60 seconds, with the depth of the dropping voltage being 0.9 per unit (p.u) and 0.1 p.u of a nominal p.u. Due to various factors, regular voltage sags are typically verified for the load at the distribution level. A few delicate loads in high technology areas find the voltage sags to be completely intolerable. Complicated operations with a certain frequency and specific voltage sag value while distortion and oscillation could maintain the load voltage requirements.

Voltage sag typically results in the destruction of the manufacturing sector and its downtime, which is expensive and causes severe problems for customers. Electric devices, also known as consumer power devices, are used to supply the distribution system with a certain amount of energy and voltage. The difficult issue might be reduced. The DVR is intended to be a more effective solution to control voltage sag and distortion than the traditional approaches to the problem. The performance of the electricity system is measured in this work by reducing voltage sag at the distribution level using a DVR.



(a)



(b)

FIGURE 3. (a) Single line diagram of test system with DVR (b) Simulink model of the test system with DVR

Parameters	Values
Supply Voltage	415 kV
Frequency	50 Hz
Load Power Factor	0.74
Converter	IGBT (3arm-6 pulses)
Load active power	7.5 kW
Load reactive power	6.6 kVA

TABLE 1. Parameters and values of test system

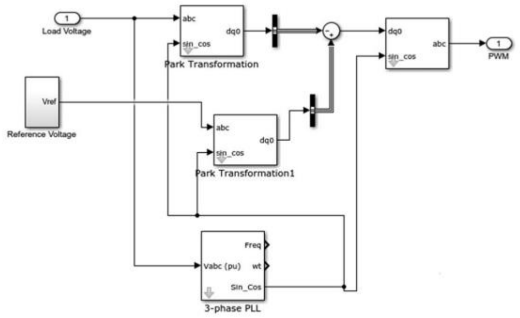


FIGURE 4. Schematic of control circuit for DVR

INTERNAL CONTROL OF DVR

The many DVR parameters and internal controls [34], as illustrated in Figure 4, are simulated in MATLAB/Simulink for control purpose. The DVR [34] should be managed in the transformer and filtering circuits at the normal supply voltage level to give the smaller amount of losses in the conversion circuits. The needed injected voltages are then delivered to the test system through the installed DVR when the voltage unbalance or distorted voltage is identified in the system. The entire process is carried out by the feedback control approach depending on the voltage (Vref) and the instantaneous value of the supply voltage (Vsupply). When the gate pulses deliver the VSI to regulate the load voltage at the control algorithm's reference voltage, the reference voltages (Vref) are retrieved by the control algorithm from the supply and the load voltages.

By calculating the issues between the dq-frame voltages of the load voltage (VLoad) and the reference voltage, it is possible to detect voltage distortion in this stage, including voltage sag and voltage swell (Vref). By coupling the load voltage to a transformation block, the abc frame is transformed into -frames. In the event that any voltage swelling or sag is detected, the reference voltage will generate the gate pulses by equating the reference voltage (Vref) with that of the load voltage (VLoad). These pulses will be received by the VSI, and by using pulse width modulation (PWM), the preferred voltage will be formed in a way to keep the load voltage at the (Vref) or reference voltage, which is 330V.

III. PROPOSED METHOD

Fuzzy logic Controller:

The non-linearity's existing in the power systems such as the possession of non-linear features and exposure to network disturbances can be dealt using the FLC. The schematic representation of such FLC is depicted in Figure 5. The structure of the FLC as shown in the following figure is made of three important components like the Fuzzier, interference engine, and Defuzzifier. In the Fuzzifier, the Fuzzification process takes place where the MFs (i.e., Membership Functions) take care of converting the two inputs to the fuzzy sets between the limit of 0 and 1.

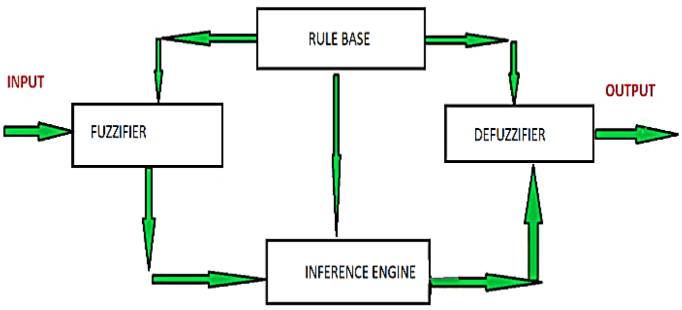


FIGURE 5. Fuzzy logic controller

The FLC membership functions and rules, which are utilized in this research work, are shown in Figures 6, 7 and 8. The triangular type of MF is used in this work along with the overlap which is made using seven different types of linguistic variables such as Zero (Z), Positive Big (PB), Positive medium (PM), Positive Small (PS), Negative Big (NB), Negative medium (NM) and Negative Small (NS).

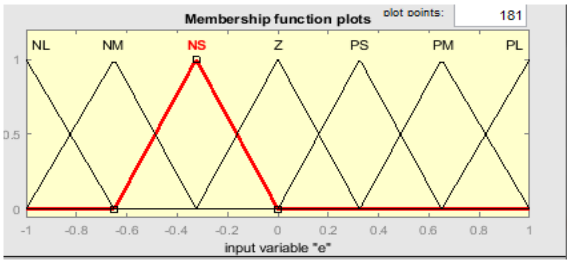


FIGURE 6. Membership function of input variable “e”

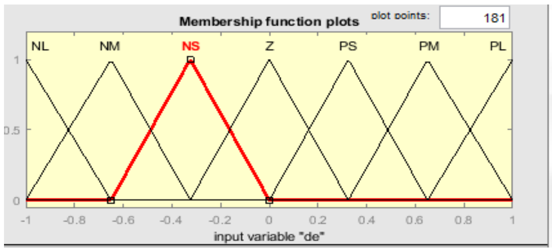


FIGURE 7. Membership function of input variable “de”

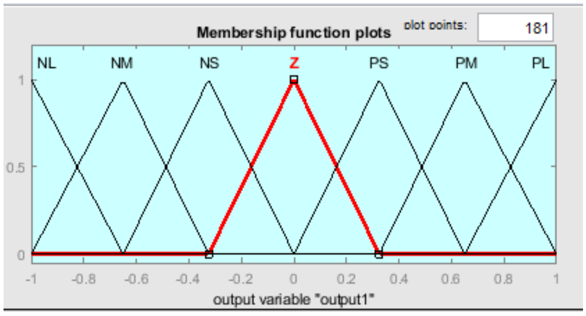


FIGURE 8. Membership function of output variable

E/CE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NM	NM	NS	Z
NM	NL	NM	NM	NS	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PM	PM	PL
PL	Z	PS	PM	PL	PL	PL	PL

TABLE 2. FLC Rules

IV. SIMULATION RESULTS AND DISCUSSION

The proposed system is implemented in MATLAB/SIMULINK software. It displays the test system's single line diagram without a DVR. It demonstrates that the test system comprises three phases, a programmable voltage source, an RL source, and is linked to a sensitive active load and reactive load. The testing system's parameters and values are shown in Table 1 above.

A potential DVR model for the power system in Simulink after the simulation was performed with a 3-phase test system without a DVR connected to sensitive loads. In MATLAB/Simulink, the simulations were conducted using a 3-phase test system with and without a DVR attached to sensitive loads. Figure 3 (a) displays the test system and DVR's single line diagram, and Figure 3 (b) displays its Simulink representation (b).

The proposed system is tested under to scenarios.

SCENARIO-1:

INJECTION OF 3rd HARMONIC

In scenario 1, the 3rd harmonic voltage is inserted into the supply voltage programmable source. The 3-phase sensitive loads are connected with this distorted supply and examined with this distortion in all three phases. Figure 9 shows that the insertion causes a distortion in voltage profile, and load voltage has observed a distorted voltage (VLoad) with a disturbing waveform, and some swell in it. The VRMS phase to phase peak reaches to near 460V magnitude in voltage profile. The disturbance in the voltage profile may lead to failure or malfunctioning of sensitive equipment.

Such systems are not accepted because they are not according to the IEEE standards. Referring to the IEEE standard 519 to 1992, the THD rate must be 5% less than the fundamental frequency. The value of THD is way over IEEE Standards. Thus, the disturbance in the voltage source is mitigated by the inclusion of DVR.

To maintain the THD distortion under the IEEE limit and improve the power quality, DVR with a proposed control system is implemented. The load voltage with DVR, along with the control system, is shown in Figure 9. The compensation in the load voltage (VLoad) can be seen in all three phases of voltage. This is accomplished with the automatic connection, and the injection of the voltage occurs when the breakers of the circuit open in the presence of the DVR. A significant reduction is seen from t = 0.1 to 0.3 sec for the voltage swell as well as the high magnitude of harmonics is removed, and voltage profile is back to normal in all the three cases with a slight flicker at 0.1 sec or 0.3 sec only. A smaller spike has been observed at 0.1 and 0.3 sec. To maintain the power quality, DVR has injected the voltage into the distribution line, the injected voltage with PI and FLC for all three phases are shown in Figure 10 and 11 respectively.

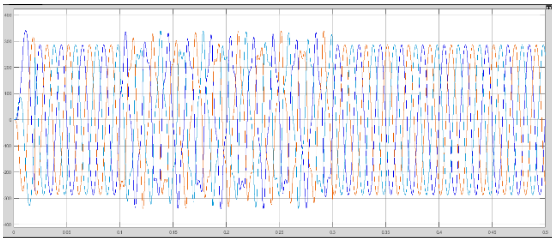


FIGURE 9. Distorted signal (V Load) in test system without DVR (Scenario 1)

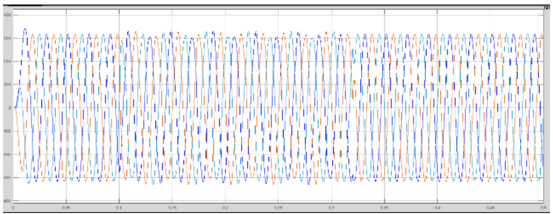


FIGURE 10. Compensated signal (V Load) in test system With PI-DVR (Scenario 1)

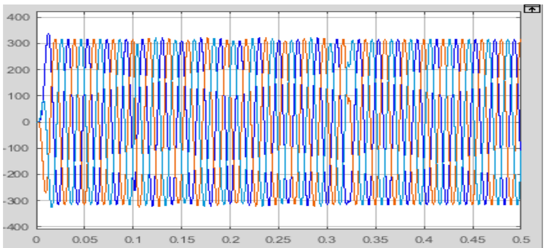


FIGURE 11. Compensated signal (V Load) in test system With FLC-DVR (Scenario 1)

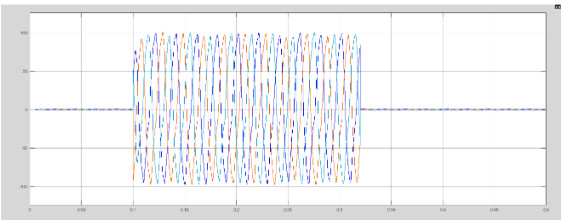


FIGURE 12. Injected voltage (V in) by DVR in all three phases With PI (Scenario 1)

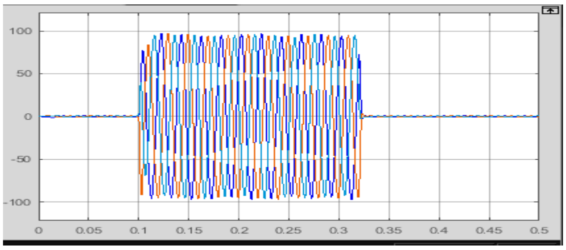


FIGURE 13. Injected voltage (V in) by DVR in all three phases With FLC (Scenario 1)

SCENARIO-2:
INJECTION OF 5th HARMONIC

In scenario 2, the parameters of the programmable voltage source are changed with 5th harmonics insertion. The duration of change in supply voltage was set to 0.1 sec to 0.4 sec in this scenario. It has also resulted in a distorted voltage waveform with almost identical shapes for all three phases, as shown in Figure 13.

The injected voltage by the DVR is shown in Figure 17 and 18. The comparison between both scenarios and their THD is presented in table 3.

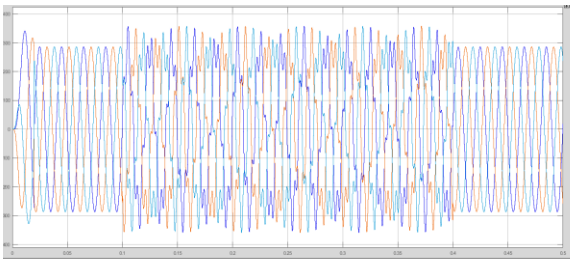


FIGURE 14. Distorted voltages (V Load) profile without DVR (Scenario 2).

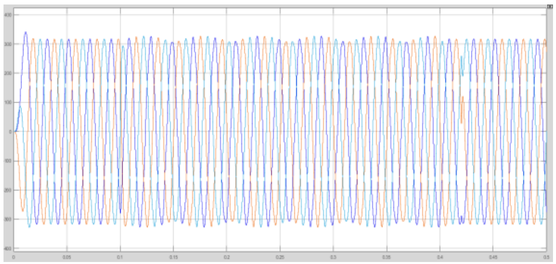


FIGURE 15. Compensated voltages profile with PI-DVR (Scenario 2).

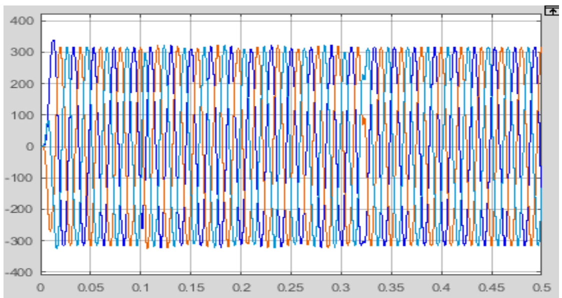


FIGURE 16. Compensated voltages profile with FLC-DVR (Scenario 2).

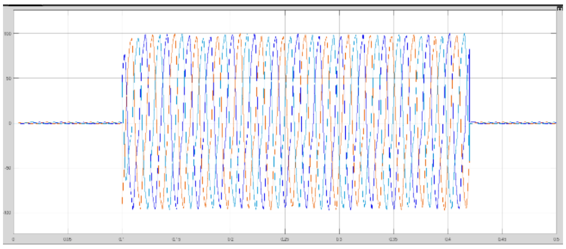


FIGURE 17. Injected voltage by DVR in all three phases with PI (Scenario 2).

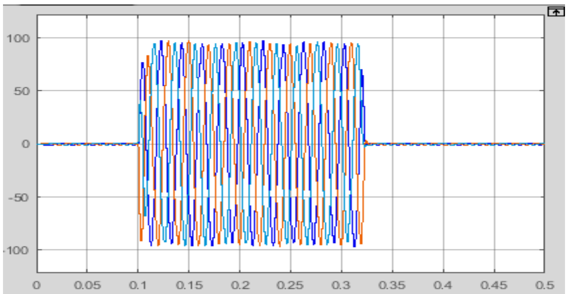


FIGURE 18. Injected voltage by DVR in all three phases with FLC (Scenario 2).

The below table shows the THD comparison between the DVR without controller, DVR with PI controller and DVR with FLC

Scenarios	Load Voltage	With out (THD %)	PI (THD %)	FLC (THD %)
1	VLa	18.45	4.62	2.03
	VLb	18.92	4.65	2.05
	VLc	18.60	4.67	1.98
2	VLa	25.68	3.38	1.96
	VLb	24.01	3.31	1.99
	VLc	24.68	3.43	1.92

TABLE 3. THD comparison

From the above table, it is clear that FLC is more accurate compare to PI controller and without DVR.

V. CONCLUSION

DVR is proposed as the most noteworthy device to enhance the quality of power and proved to be a useful and well-performing device. Through the platform of MATLAB/ Simulink, a simulation of DVR with a power circuit is carried out by structure modelling of the control circuit and power system with a sensitive load. The DVR with Fuzzy Controller is implemented with the test system and also investigated with PI- DVR and without DVR. A programmable voltage source is used to supply a distorted voltage; first with 3rd harmonic and then with 5th harmonic insertion in the supply voltage. To maintain the load voltage normal and steady at the optimal range, the correction of any problem in voltage supply is possible when the DVR injects the suitable voltage component into it. While maintaining the compensation of voltage profile, the THD was reduced from around 4% to 2% with FLC-DVR. The proposed DVR with Fuzzy based control strategy is effective in compensation of the distorted load voltage and maintained a better steady and smooth voltage profile with very less harmonic content in it.

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