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Remote Monitoring for Solar Photovoltaic Systems in Rural Application using GSM Voice Channel

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Abstract

The health of the Solar PV systems should be monitored continuously for their better performance and maintenance. For PV systems installed at rural locations, remote monitoring capabilities provide the information in advance when system performance is degraded or is likely to fail. Based on this information, preventive maintenance can be carried out to improve the performance and life of the system, thereby reducing the overall operating cost.
Advantages and disadvantages of several monitoring systems for rural application, based on the techniques of communication, such as, computer to computer communication (Ethernet), embedded system to computer (GSM) and embedded system to embedded system (GSM, GPRS) are discussed.
A new technique is proposed as a solution to overcome the limitations of other techniques. The proposed technique uses GSM voice channel for the communication of data, in the form of analog signal between transmitter and receiver. In order to study and evaluate the performance of proposed technique, various experiments have been performed and impact of parameters like shape (sine, square and triangular), frequency (50 - 4000Hz) and amplitude (0 – 6 V) of analog signal have been studied. It is observed that sine wave of frequency from 300 Hz to 3300 Hz with 4.5 V maximum amplitude can be sent on voice channel of GSM network with less than 1% error. This technique has low initial as well as operating cost. The GSM network is readily available in rural areas; this technique can be used easily.

Keywords: preventice maintenance, analog signal, solar power plant,

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*This technique is also communicated for the patent with registration no 1959/MUM/2013.

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1. Introduction

Clean solar electricity can be generated by solar photovoltaic as well as by solar thermal technologies. The contribution of solar electricity in the world's total electricity generation is currently small percentage of total world energy production (0.2%) (Corresponding to 72 GW_p capacity of solar plants as compare to 3600 GW_p capacity of generated power plants) [1], but it is increasing at very high rate. During the last several years, the average annual growth rates of renewable energy capacity have been 70% [1]. In order to promote installation of solar power plants in India, the Government of India has also announced a national mission called Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 [2].

As per the JNNSM, the set target is to install 20 GW_p solar power capacity in India by year 2020 [2]. The planned capacity is nearly equally distributed among solar PV (SPV) and solar thermal technology. The JNNSM target includes installation of grid connected SPV systems as well as standalone or off-grid SPV systems. In this mission, the target is to install 18 GW_p of grid connected solar power plants (including solar PV & solar thermal) and 2 GW_p of standalone SPV systems.

Significant attention has been given to the installation of standalone SPV systems in JNNSM because standalone system is an immediate solution for the areas where the grid infrastructure is still absent or there is frequent power cuts, which is true for several parts of India. The SPV power systems are installed generally in remote rural areas. Since these power plants are away from the urban areas they are not easily approachable, therefore the repair and maintenance services in remote areas are expensive and time consuming. Due to above reason the standalone SPV systems installed in remote rural areas many times fails. For smooth, safe and optimum operation, SPV systems should be regularly monitored and evaluated. Also, due to distributed nature of installation of standalone SPV systems it will be very costly and tedious job to implement the remote monitoring & maintain the individual SPV system independently [4]. A centralized remote monitoring of SPV system will be more efficient and cost effective [3]. The remote monitoring system reduces the cost of system operation and maintenance by preventing the need of deployment of any trained technician or expert at the site. An off-grid SPV system consists of Solar modules, MPPT, batteries and inverter. In this system battery is a most week component. The batteries should be charged and discharged within its respective voltage levels. If they are not monitored and maintained timely, batteries are going to degrade at faster rates. This can be one of the sufficient reason for the system failure.

1.1. Remote Monitoring System

In remote monitoring system, parameters of SPV system are measured by sensors, processed by signal processors and information is sent electronically to a central location where an operator can monitor and take appropriate action, if required. The basic remote monitoring system consists of two units; transmitter at remote location (where SPV system is installed) and receiver at central station (from where SPV system monitoring process is done). Transmitter and receiver can be small embedded system or can be computer based system. Based on type of system used at remote location and central station, remote monitoring system can be categorized in following ways:

- Computer (remote) to Computer (central) remote monitoring system [*5*]
- Embedded system (remote) to Computer (central) remote monitoring system [*3,6*]
- Embedded system (remote) to Embedded system (central) remote monitoring [*7*]

All remote monitoring systems use different communication techniques for data transmission, for example computer based remote monitoring system can use Ethernet network or dial-up network for the communication. The embedded remote monitoring systems can use Ethernet network, dial-up network or GSM modem for communication. The GSM modem can be used for communicating in two ways; through General Packet Radio Service (GPRS) or Short Messaging Service (SMS). Each of the technique of communication mentioned above has their own advantages and disadvantages. In Ethernet communication, repeater has to be deployed at every 100m of wire [8]; in GPRS communication there is issue of dynamic IP allocation [9] and in SMS mode of communication there is issue of the delay introduced by the network in delivery of the SMS [6]. This delay can range from few hours to some days or it can fail permanently.

To solve above problems a new technique has been proposed for data transmission and reception. This technique overcomes all the shortcomings mentioned above for various modes of communications. This technique is more user friendly, reliable, real time and has low initial as well as operating cost as compare to all other techniques.

2. Limitations of current communication systems for monitoring SPV system installed at remote areas

Typically remote monitoring system installed in remote rural area will be of small capacity, so in this case cost of remote monitoring system can be significant and will impose a limitation on system.

Ethernet: computer networking technology is used for Local Area Network (LAN). It is an IEEE 802.3 standard. Ethernet can also be used for sharing, sending or receiving the data between computers. For Ethernet, there is a need of CAT5 (category 5) cable connected to computer. This wire can transmit or receive the signal within 100 meters. There is need of repeaters for every 100 meters of the wire stretched for communication which adds huge extra cost in the installation of Ethernet for communication. This is not feasible for the rural areas [8]. The extra cost for installation depends on the distance from the internet source to the rural area.

GPRS using GSM: GPRS is a data communication service available wirelessly (in wireless mode) on the 2nd generation GSM network. The GPRS communication is done through the packets of data. The procedure for establishing connection to the internet is shown in Figure 1. Initially the GSM modem sends request to the GSM network; in reply GSM network assigns the temporary IP to the modem and connects the GSM modem to the internet [9]. The GSM modem directly connects to the internet, which adds extra cost for downloading and uploading of data

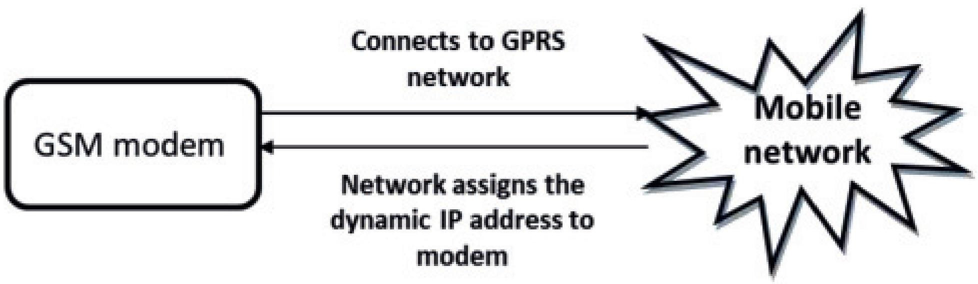

Fig. 1. Procedure to connect GSM modem to internet

In this arrangement, every time when GSM modem sends a request to GSM network for connection to internet it allocates different IP address. Programming is done assuming a fixed IP address for transmission and reception. This becomes difficult for any system to deal with dynamic IP allocation. To resolve this issue one has to deal with complex programming.

SMS using GSM: SMS is one of the simple and cheap ways for communication over GSM mobile network. SMS can contain 160 alphanumeric characters [10]. These characters can be coded for security reasons or they can be directly utilized as data as per the requirements. Sometimes congestion in the GSM network can lead to the delay in delivery of the SMS. The delay can vary from few minutes to few hours. In some cases the SMS delivery can fails permanently. Therefore, there is issue of reliability with SMS communication [9].

2.1. Cost comparison of various systems:

Considering a remote monitoring system for 1 kWp standalone SPV plant installed at the remote location. The remote monitoring systems implemented in different method are listed in Table 1 with their initial and recurring/ operating costs per year as compare to the total cost of the SPV system.

Table 1: Percentage cost comparison of various remote monitoring system to total cost of system

Sr No.	System	Technology	Cost of remote monitoring system * (Initial + operating)
1	Computer to computer	Ethernet	25
2	Embedded System to Computer Based	GPRS / GSM	22
3	Embedded system to Embedded system	GPRS / GSM	13
4	New Technique proposed	Mobile	5

*All costs are in part percentage (%) with respect to overall SPV system cost (%)

As seen from table1 the initial cost of remote monitoring system reduces from computer to the embedded system approximately from 25% to 13% of total system cost. There is significant decrease in cost for the new proposed technique, which is 5% of the total cost of the SPV system. Figure 2 shows the bar graph of percentage cost of the remote monitoring and overall system.

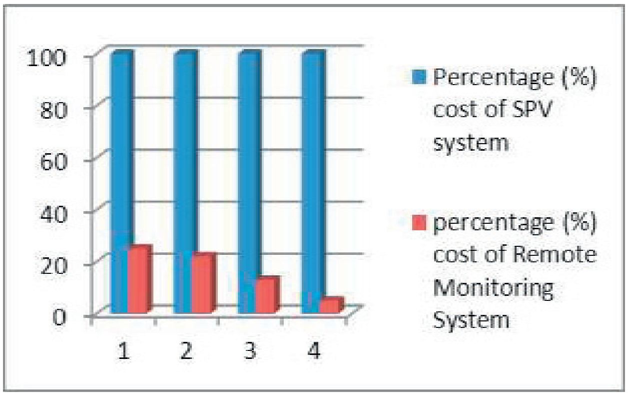

Fig. 2. Graph of percentage cost comparison of various SPV system and remote monitoring system

The portion of bar graph shown in black color is percentage cost of remote monitoring system and the portion in the grey color is the Solar PV system cost. The minimum cost percentage of the conventional remote monitoring system is about 13% of the overall system cost whereas the new method proposed cost of is only 5% of the total cost. The cost of this remote monitoring system can reduce further when the mass production is introduced.

3. Proposed technique for data transmission and reception (PV system monitored using voice channel of GSM network)

Considering limitations of existing communication techniques from the prospective of low cost & effective monitoring for standalone Solar PV system installed remotely, a new technique is proposed. In this technique the voice channel of the GSM network is proposed to be utilized.

In this technique of communication, data is sent in the form of analog signals of various frequencies on the voice channel of GSM network. There are two locations: one remote location (where the SPV system is installed) and other location is called central station (where data monitoring and processing is done). At both locations, embedded systems are installed. The data transmission is initiated by the user by making a call from mobile phone at remote location, which is received by the mobile phone at the central station automatically. The data reception is automatically done. In this system, the initial as well as the operating costs are very low. Various experiments were performed for evaluating effectiveness of transmission and reception of analog signals on voice channel of GSM network.

The audible range of the voice frequency for humans is from 20 Hz to 20 kHz. In telephony voice frequency band used for communication varies from 300 Hz to 3400 Hz [10]. Similarly the frequency range for data transmission and reception can be varied from 300 Hz to 3400 Hz in order to utilize the voice channel of the GSM network for data communication.

3.1. The embedded system at remote location:

The embedded system installed at remote location will have various sensors for measuring parameters like voltage, current, power, temperature and radiation related to standalone SPV system. The output of these sensors is given to signal processing unit, which processes various signals and converts them into voice type analog signals for the transmission on GSM voice channel. The transmitter device used in this technique is a mobile phone. The standalone SPV system that need to be monitored is connected to the mobile phone through the earphone jack of mobile phone and then phone number of central station is dialed as shown in Figure 3.

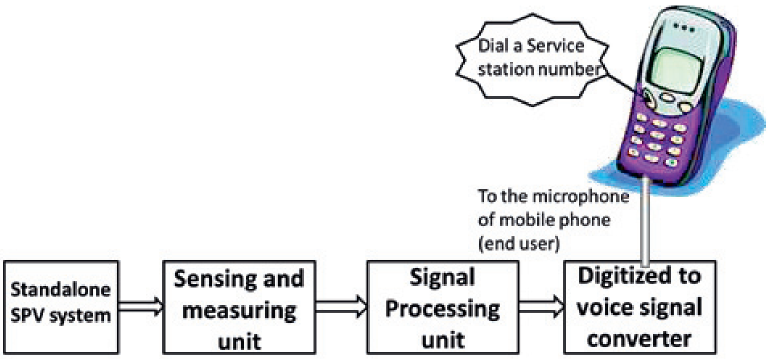

Fig 3. Embedded system at remote location for data transmission (remote monitoring center)

3.2. The embedded system installed at central station:

The embedded system installed at the central station receives the call made by the user at remote location and collects the signal for remote monitoring on GSM voice channel. In this process, the head phone jack of mobile phone is connected to the signal converter, which converts the signal as desired through signal processing unit. As shown in figure 4 the converted signal is given to the signal processing unit which processes the signal and extracts data from it. The extracted data is used by data analysis unit to evaluate the health of SPV system. Then according to the condition of the remote system, appropriate decision is taken and the status of system is sent through SMS or call to the service engineer and to the end user.

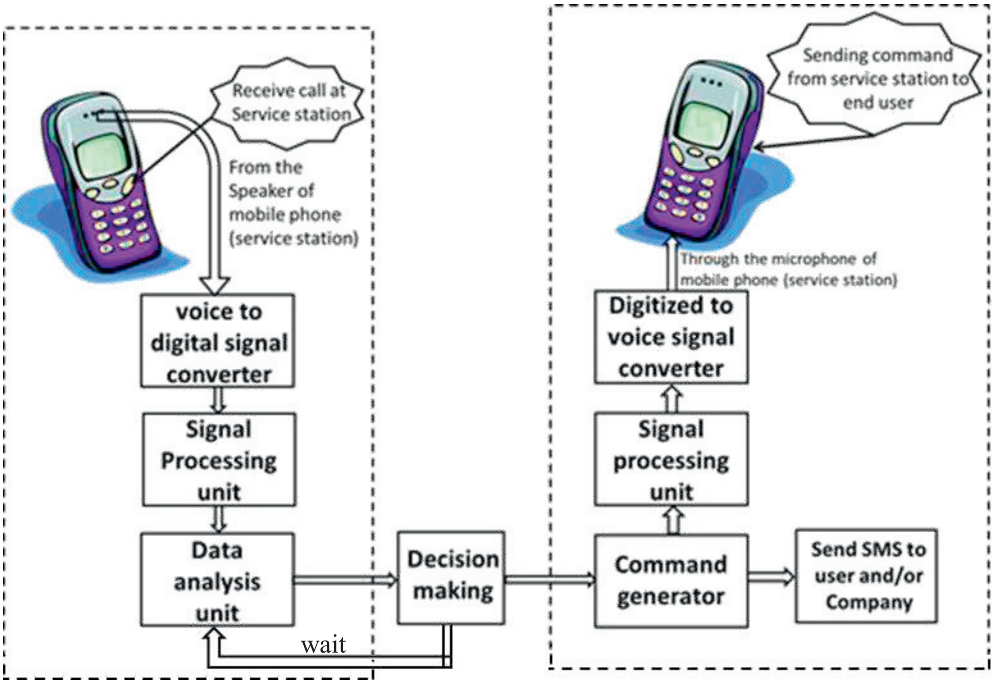

Fig 4. Unit installed at central station (data receiving and processing center)

Decision making unit in central station takes the decision and generates the command appropriately and send the SMS/E-mail to the user and/or service engineer for further preventive action. At the same time, while the call is still in process from end user to the service station the data in form of voice signal or SMS is sent to the user as shown in figure 4. The end user receives the data about the health of the system either through SMS or voice command on mobile itself and he can take appropriate action depending on the condition of the system if there is a general fault otherwise service engineer will get SMS for the repair work. With this technique simple instructions like "your system is working fine " or "Clean the SPV module" or "replace the old battery" or "reconnect all connection to avoid loose contacts" can be sent through SMS or interactive voice response system (IVRS) directly to the user to take appropriate action without any need of expertise on SPV system. The cost of this system is fixed and the operating cost depends on the number of time the remote monitoring system is used by the user and calls are made to the central station.

This technique can also be well incorporated with other remote monitoring system also. The voice channel of any communication system like GSM, 2G, 3G, CDMA, PSTN, etc. can be utilized for the data transmission and reception. This technique is also being applied for the patent (1959/MUM/2013).

4. Results and discussions

Various experiments were performed in order to study and evaluate the transmission of analog signal on the GSM voice channel. Transmission and reception of any analog signal between transmitter and receiver can be characterized by 4 parameters

- Shape of transmitted and received signals
- Frequency of transmitted and received signals
- Amplitude of transmitted and received signals
- Distance between transmitter and receiver

The hardware used for this experiment is as follows:

Transmitter:

a. Frequency generator (function generator) b. Mobile Phone (Nokia 1108) c. Earphone for mobile (HDC 5)

Receiver:

a. Frequency detector (CRO) b. Mobile phone (Nokia 1110i) c. Earphones (HDC 5).

The experiments have been conducted by varying one parameter and keeping other three constant. As tabulated in the Table 2

Table 2: Percentage cost comparison of various remote monitoring system to total cost of system

Parameter	Shape	Frequency	Amplitude	Distance
1	Sine, Square, Triangular	Fixed at 1.5kHz	Fixed at 4.5 V	Fixed
2	Sine	100-3500 Hz	Fixed at 4.5 V	Fixed
3	Sine	Fixed at 1.5 kHz	0 - 6 V	Fixed
4	Sine	Fixed at 1.5 kHz	Fixed at 4.5 V	Zero to 250 m

- **Shape of transmitted and received signal**

We have considered three basic shapes of the analog signal which are sine wave, square wave and triangular wave. These wave shapes can be easily obtained by using function generator. In this experiment, the signal frequency was kept constant at 1.5 kHz and The shape of frequency were varies in following order first sine wave, triangular wave and finally square wave. At the same time received wave was observed at receiver end and following results were obtained. When sine wave was transmitted, sine wave of almost same frequency was received as shown in figure 5 (a). When square wave was transmitted, the received wave was modified sine wave with harmonics as shown in figure 5 (b). For triangular wave transmission, sine wave of corresponding to fundamental frequency of triangular wave is received as shown in figure 5 (c). This variation in reception is due to the voice channel of the GSM network, it allows only speech like signal to be transmitted. Sine wave is a closet possible voice like waveform without any harmonics, whereas the square and triangular waveform contains only odd harmonics as given by Fourier series [11]. From above experiments we can say the sine wave can be best transmitted over GSM voice channel without any distortion in shape.

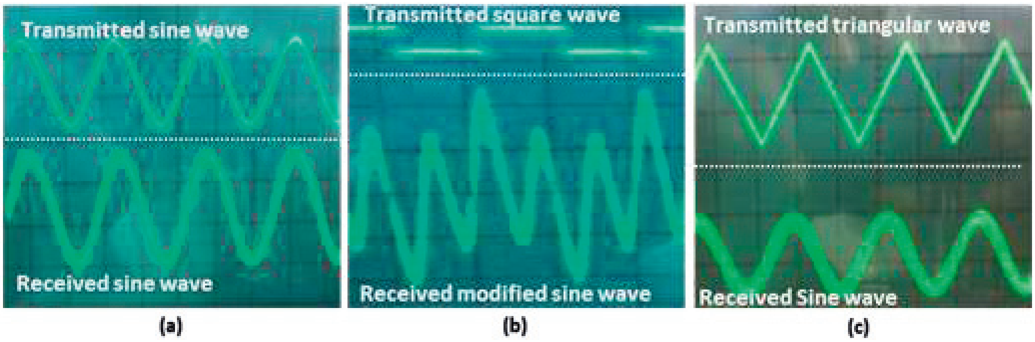

Fig 5 Observing 3 different shaped waveforms sent from transmitter and received at receiver on CRO
(a) Sine wave transmitted and received (b) square wave transmitted and received (c) triangular wave transmitted and received

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- **Frequency of transmitted and received signals**

In this part of experiment frequency of transmission was varied from 200 Hz to 3500 Hz to evaluate the actual frequency range for transmission over GSM voice channel. The transmission and reception of signal was observed at both the ends. The difference between transmitted and received frequency was

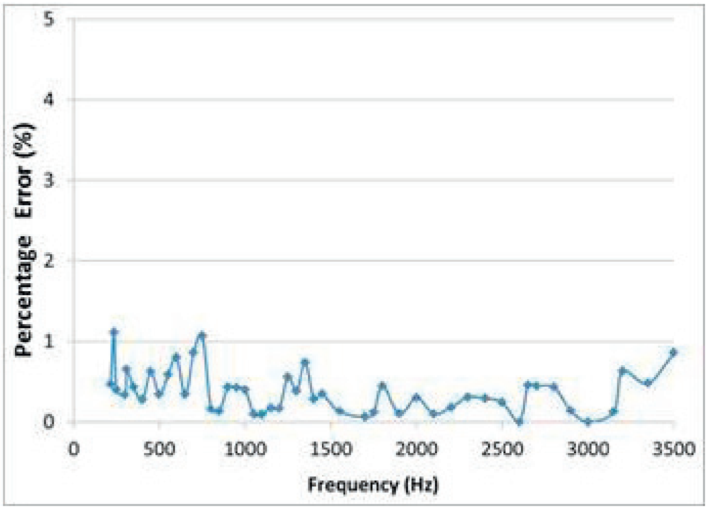

Fig 6 Graph of percentage (%) error in reception vs. transmitted frequency

calculated in percentage (%) and the percentage error vs. transmitted frequency graph is plotted as shown in Figure 6. The maximum error percentage was measured and calculated to be less than 1%. But generally, if frequencies range is 200 Hz - 1100 Hz percentage error is more as compare to the frequency range 1100 Hz - 3400 Hz

- **Amplitude of transmitted and received signals**

In this experiment the transmission voltage was varied from 2 V to 6 V and results were observed at receiver. The received signal faithfully represented transmitted signal for 2 V to 4.5 V. when transmitted voltage was increased beyond 4.5 V, the clipping in the waveform was noticed as shown in figure 7

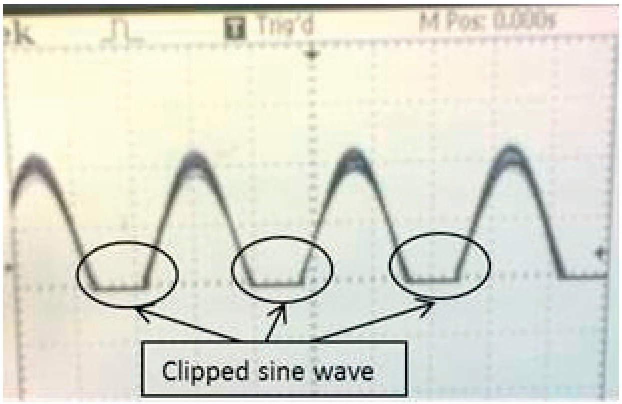

Fig 7. Snap of clipping of wave shape transmitted beyond 5.5 V signal observed on CRO

- **Distance between transmitter and receiver**

In this experiment the distance between transmitter and receiver was varied. Initially, the transmitter and receiver both were kept in the same laboratory, then the transmitter was moved to another laboratory and receiver was kept in same laboratory for transmission and reception of analog signal and waveforms with their respective transmission and reception of frequency was observed. The difference in transmitted and received frequencies was calculated. As expected, distance between transmitter and receiver does not affect percentage error in transmission and reception of the signals. As per the basic of mobile communication, every mobile phone is connected to the base station of its network service provider first and then it connects the call to the respective service provider of desired destination mobile phone. The distance does not matter in communication of two mobile phones.

Conclusion:

Various remote monitoring configurations have been studied and issues related with each communication technique have been also discussed. A new technique has been proposed for communication using GSM voice channel for communication of data between transmitter and receiver. The data in form of analog signal of different frequencies and shapes are sent on the voice channel of GSM network and received at receiver end. From experimental results, parameters like shape, frequency range and amplitude are evaluated. For sine wave, received wave is without any phase shift. The frequency of transmission can be done in 300 Hz to 3300 Hz. Maximum percentage error in the received signal is less than 1.2%. The amplitude range of 3.5 V to 4.5 V is best suitable for proper reception. The new proposed technique is cost effective and technologically simple to implement as compared to other configurations.

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