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POWER QUALITY DISTURBANCES AND OPERATIONAL EVENTSDETECTION IN HYBRID POWER SYSTEM

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ABSTRACT

Requirement of green supply with higher quality has been consumer's demand around the globe. The electrical power system is expected to deliver undistorted sinusoidal rated voltage and current continuously at rated frequency to the consumers. Power quality (PQ) problem is the deviation of voltage and current from their standard waveforms. The deviation of the frequency from its standard values of 50 or 60 Hz is also the power quality problem commonly observed in the power system network. Power quality disturbances increase the risk of black- out; especially because of the failure of interdependencies between sub-networks and associated dynamical propagations. PQ disturbances also affect the performance of the consumer equipments as well as the equipments in the power system network such as protection equipments, control and relay system etc. It has recently acquired intensified interest due to wide use of power electronics, microprocessor based devices, controllers in industrial processes, non linear loads and proliferation of computer network.

Keywords: solar photovoltaic system, renewable energy ,wind energy conversion system ,wind turbine rotor blades, power quality ,voltage Sag ,voltage swell, voltage flicker, voltage interruption, waveform distortion, voltage fluctuation

I. INTRODUCTION

This chapter briefly discusses the introduction of proposed research work focussed on the detection of operational events in the hybrid power system and power quality disturbances associated with these events using signal processing techniques. The detailed scope of research work and organization of the thesis is also presented in detail.

General

The power quality (PQ) problem is the deviation of voltage and current from their standard waveforms as well as frequency from its standard values of 50 or 60 Hz. The various power quality disturbances include voltage sag, swell, voltage interruptions, fluctuations, harmonics, impulsive transient and oscillatory transients. These disturbances cause failure or mal-operation of electronic equipments, industrial drives, computers, end user electric gadgets etc. [1]. Operational events such as outage of the renewable generators, grid synchronization of the renewable generators and islanding of the test system from the utility grid produces power quality disturbances in the renewable energy sources based hybrid power system.

Digital signal processing techniques like the Fourier transform (FT), short-time Fourier transform (STFT), wavelet transform (WT), Kalman filter, and Stockwell transform (ST) can be used for detection of operational events and the power quality disturbances associated with the these operational events using the time and frequency domain information of the operational events and PQ disturbances. The FT does perform with low efficiency for detection of power quality signals which are mostly non-stationary in nature. STFT decomposes the non-stationary signal into the time–frequency domain by considering it as a concatenation of stationary signals within the sliding window. Wavelet analysis allows the use of long time intervals for precise low frequency information and shorter regions for high frequency information. The ST combines the elements of WT and STFT but falls in different category. It uses an analysis window whose width is decreasing with the frequency, providing a frequency-dependent resolution [2].

II. THEORETICAL CONCEPTS OF HYBRID POWER SYSTEM AND POWER QUALITY

This chapter presents basic theoretical concepts of the power system, power quality disturbances wind energy conversion system and solar photovoltaic system along with the characteristic curves of solar PV system.

Power System

The electric power grid is a complex interconnected system that may be subjected to blackouts and external disasters like hurricanes. It is necessary for utilities to repair and restore their power system as quickly as possible during extreme conditions. State estimation helps to get a better picture of the power system with an available set of measurements. The fundamental major feature which concern of Power System are

Basic Concept's of Power

In simple term power is define as the rate of doing work. Power = work/time. There are three types of power

- Active power
- Reactive power
- Apparent power$\frac{work}{time}$

Apparent Power (S)

It is defined as the product of r.m.s value of voltage (V) and current (I). It is denoted by (S) Volt ampere

P=VI

It is measured in unit Volt-ampere (VA) or Kilovolt ampere (KVA).

Active /Real /True Power (P)

It is defined as the product of applied voltage and the active component of the current. It is real component of the apparent power. It is measured in unit watt (W) or Kilowatts (W).

P = VIcos (phi)

Reactive Power (Q)

It is the defined as the product of applied voltage and the reactive component of the current. It is represented by Q and it is measured in unit volt- ampere (VAR) or kilo-Ampere Reactive (KVAR).

Q = VIsin(phi)

III. SOLAR PHOTOVOLTAIC SYSTEMS

A grid-synchronized Photovoltaic (PV) system consists of solar PV plates, maximum power point tracking (MPPT) system, boost converter, inverter, grid coupling inductor and capacitor, transformer etc. The single diagram of grid connected solar photovoltaic system with various components is shown in fig.

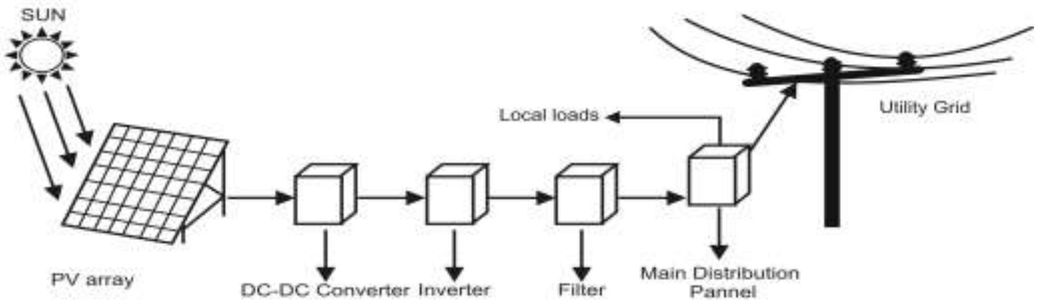

Fig. 1 Grid-connected solar PV system

Photovoltaic Characteristic

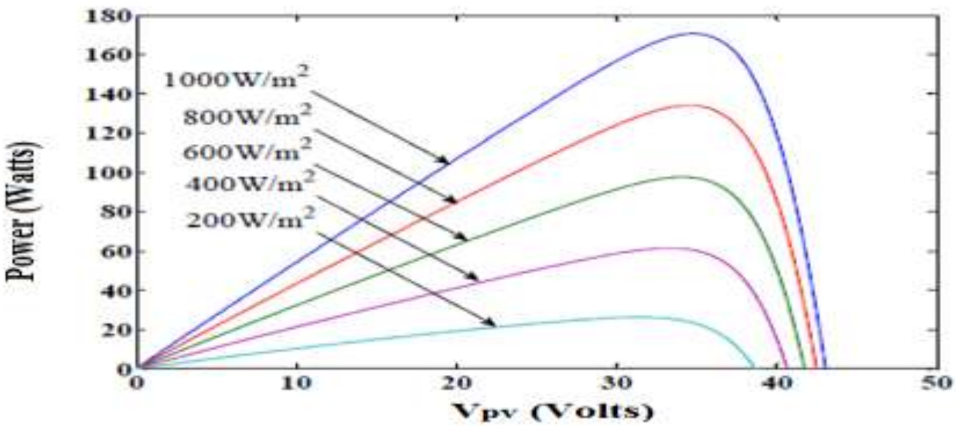

Fig. 2 Irradiance effect on P-V Characteristic at Constant Temperature (25^{o}C)

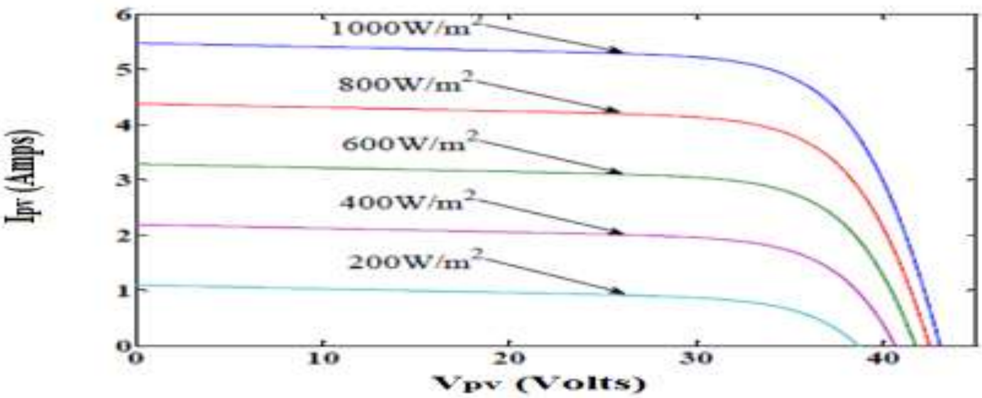

Fig. 3 Irradiance effect on I-V Characteristic at Constant Temperature (25^{o} C).

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IV. WIND ENERGY CONVERSION SYSTEMS

A wind energy conversion system converts kinetic energy of the wind into mechanical energy by means of wind turbine rotor blades which is converted to electrical power by generator and is being fed to the utility grid through power electronic converters. The wind plant collector design working group of IEEE divides WECSs based on electric generator, utilised power electronic converter (PEC), behaviour during disturbances, and speed. However, manufacturers classify as WECS with and without PEC. The WECS without PEC is mostly based on squirrel-cage induction generator (SCIG) and operated in direct connection to the host grid as shown in Fig.

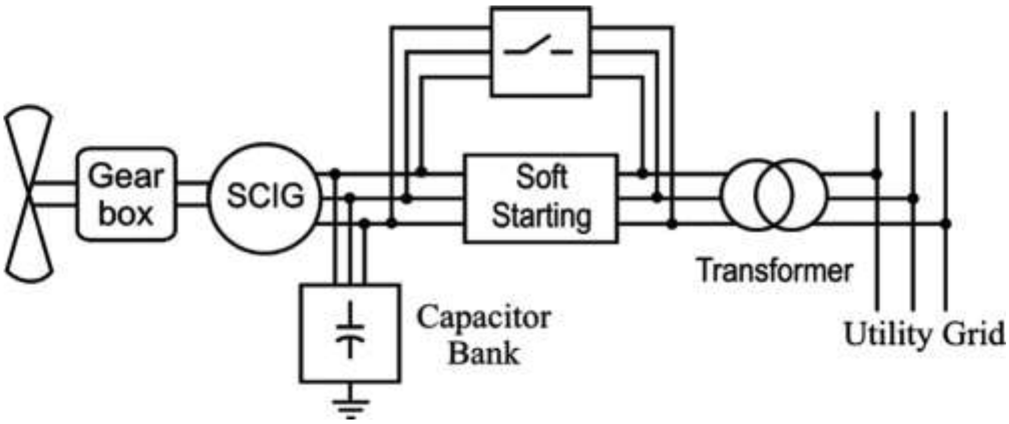

Fig. 4 Wind energy conversion system without PEC.

V. POWER QUALITY ISSUES

Power quality is a simple term, yet it describes a multitude of issues that are found in any electrical power system and is a subjective term. The concept of good and bad power depends on the end user.

Voltage Sag

A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 minute is defined as voltage sag.

Voltage Swell

A swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.

Voltage Flicker

Flicker (or light flicker, as it is sometimes called) is a low-frequency phenomenon in which the magnitude of the voltage or frequency changes at such a rate as to be perceptible to the human eye.

Voltage Interruption

An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min. Interruptions can be the result of power system faults, equipment failures, and control malfunctions.

Voltage Fluctuation

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges specified by 0.9 to 1.1 pu.

Power Frequency Variations

Power frequency variations are defined as the deviation of the power system fundamental frequency from it specified nominal value (e.g., 50 or 60 Hz). The power system frequency is directly related to the rotational speed of the generators supplying the system.

VI. PROPOSED TEST SYSTEM AND MATHEMATICAL TECHNIQUES USED FOR PROPOSED ALGORITHMS

This chapter describes the proposed test system of the renewable energy sources based hybrid power system used for the investigation of the detection of the operational events such as outage of the renewable energy generators, grid synchronization of the renewable energy generators and islanding of the test system from the utility grid using the Stockwell transform and Fuzzy c-means clustering and power quality disturbances associated with these events using the Stockwell transform based algorithm.

Test System Used for Propose Study

This section describes the test system which has been utilized as renewable energy sources based hybrid power system used for the study of detection of the operational events and power quality disturbances associated with these operational evensts under various operating scenarios. A standard IEEE-13 bus test system is modelled as a hybrid power system by integrating the wind generator and solar PV system. The original system is a 60 Hz, 5 MVA, operated at two voltage levels of 4.16 kV and 0.48 kV.

TABLE 1 LOADING STATUS OF TEST SYSTEM USED FOR SMART GRID

Nodes	Load Model	Load		Capacitor banks (kVAr)	Generator
		kW	kVAr		
634	Y-PQ	400	290		
645	Y-PQ	170	125		
646	Y-PQ	230	132		
652	Y-PQ	128	86		
671	Y-PQ	1155	660		
675	Y-PQ	843	462	600	
692	Y-PQ	170	151		
611	Y-PQ	170	80	100	
632-671	Y-PQ	200	116		
680					Utility grid
650					Wind: 1.5 MW, Solar PV: 1 MW

TABLE 2 DATA OF TRANSFORMER OF TEST SYSTEM USED AS A HYBRID POWER SYSTEM

Transformer	MVA	kV-High	kV-Low	HV winding		LV winding	
				R (Ω)	X (Ω)	R (Ω)	X (Ω)
Substation	10	115	4.16	29.095	211.60	0.1142	0.8306
XFM	5	4.16	0.48	0.011	3.0159	0.011	3.0159
XWG	5	4.16	0.575	0.3807	2.7688	0.0510	0.0042
XSPV	5	4.16	0.260	0.001	1.1310	0.001	1.1310

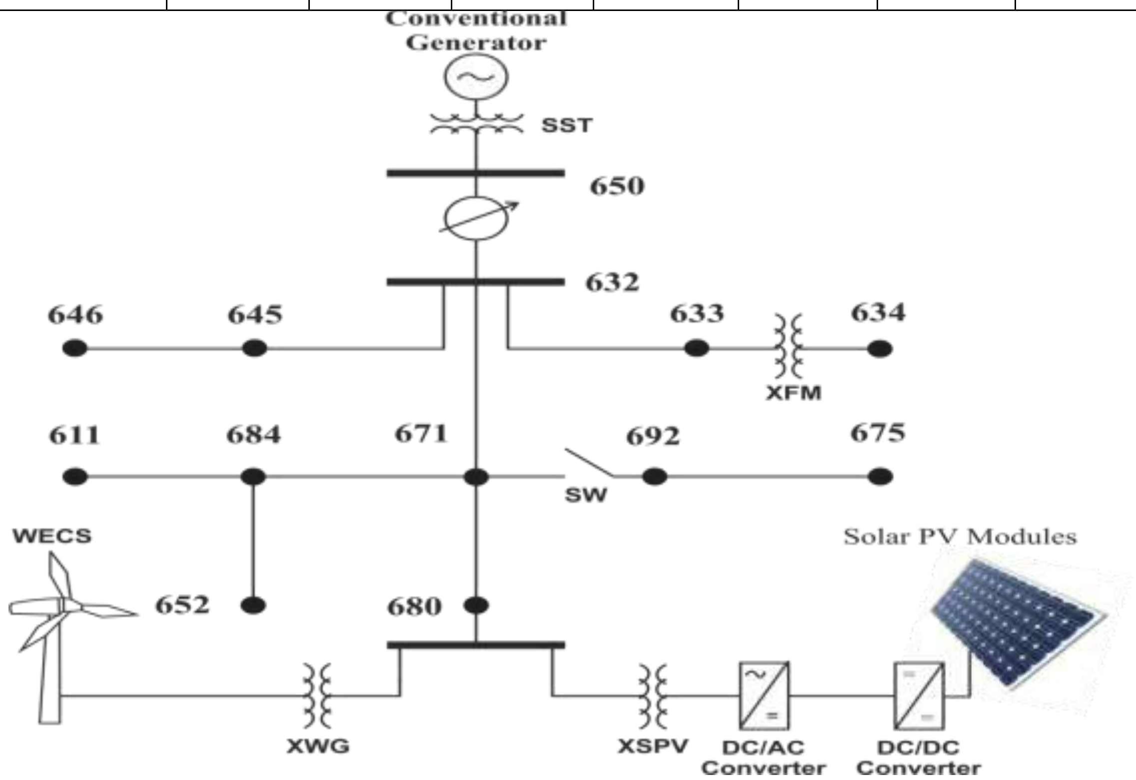

Fig. 5 Distributed generation sources based smart grid

VII. DETECTION OF OPERATIONAL EVENTS IN RENEWABLE ENERGY SOURCES BASED HYBRID POWER SYSTEM

This chapter presents an approach for the detection of operational events such as islanding of the test system from the utility grid, outage of the wind and solar PV generators from the test system and synchronization of the wind and solar PV generators to the test system. The proposed test is hybrid power system network consisting of the IEEE-13 bus test system integrated with the wind and solar PV system. The proposed study has been carried out using a standard IEEE-13 bus distribution network modeled as a hybrid power system incorporated with wind and solar PV systems. The proposed test system is simulated using MATLAB software in simulink environment. The voltage at the bus 650 of the test system has been captured and passed through the sequence analyser to obtain the negative sequence component. This negative sequence voltage is decomposed using the S-transform to obtain the S-matrix. Features extracted from this matrix are used for the detection of the operational events under investigations.

Simulation Results: Detection of Operational Events

This section details the performance of proposed methodology for the detection of events such as islanding, outage and grid synchronization of wind/solar generators under various operating scenarios. Three case studies for each of these events with wind energy, solar PV system and simultaneously with wind and solar PV systems are considered.

TABLE 3 FEATURES OF NEGATIVE SEQUENCE COMPONENT OF VOLTAGE

Event	Class Symbol	Features			
		F1	F2	F3	F4
Islanding with wind	C1	29.9403	4.9285	161.0021	12.6887
Islanding with solar	C2	22.4143	4.3069	242.5182	15.5730
Islanding with wind and solar	C3	30.9101	4.9248	121.9433	11.0428
Outage of wind	C4	34.7214	5.4917	3.6689	2.4797
Outage of solar	C5	33.0140	5.3294	1.0605	1.3172
Outage of wind and solar simultaneously	C6	36.3988	5.5970	9.0686	3.9322
Synchronization of wind	C7	13.3309	2.7593	176.2331	13.2753
Synchronization of solar	C8	4.6485	1.4784	24.5662	4.9564
Synchronization of wind and solar	C9	14.6469	2.8852	150.9827	12.2875

Detection of Islanding Events

The variance (F5) and standard deviation (F6) plots for the islanding events (classes C1 to C3) are shown in Figs.respectively.

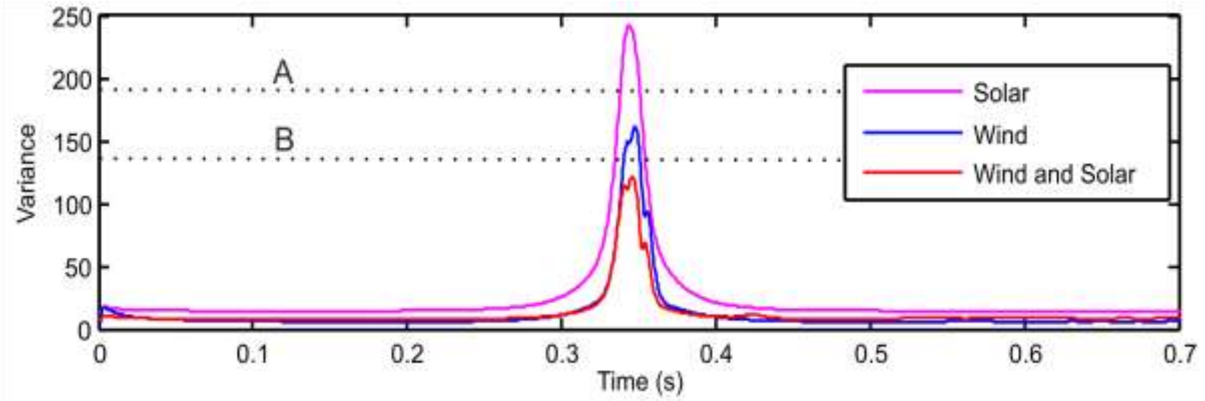

Fig. 6 Variance plots for detection of islanding using S-transform.

Detection of Outage of Generators

Figs.depict the variance (F5) and standard deviation (F6) plots for the outage of wind/solar generators (classes C4 to C6) respectively.

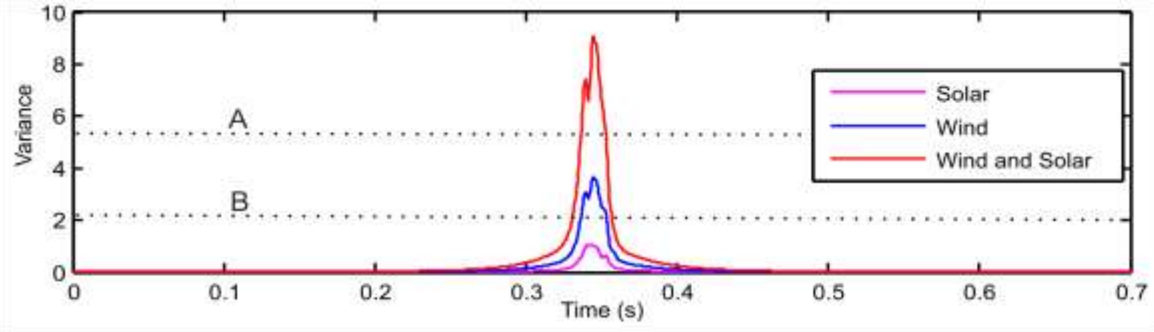

Fig. 7 Variance plots for detection of outage using S-transform.

Detection of Grid Synchronization of Generators

It has been observed that the methods based on plots of variance and standard deviation are not so much effective in the discrimination of events of grid synchronization of wind and solar generators.

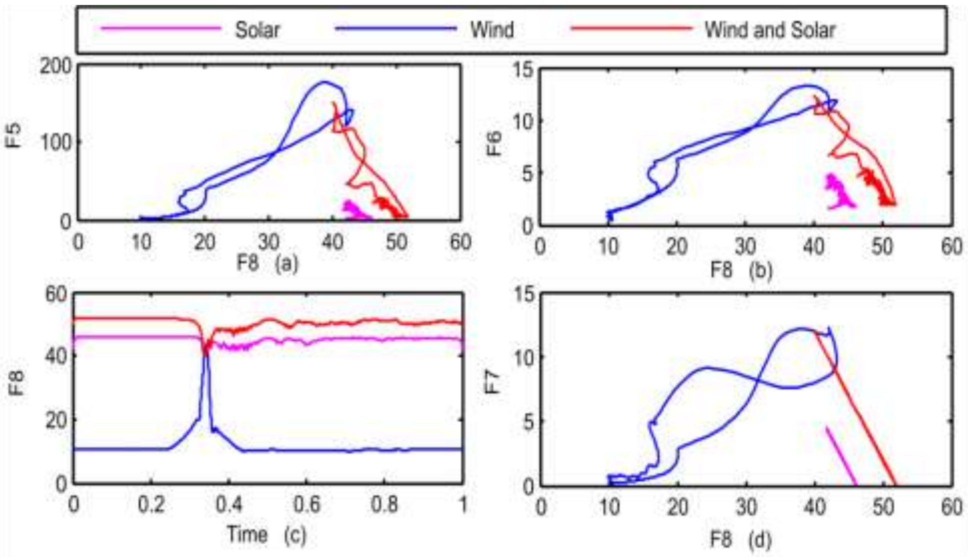

Fig. 8 Fuzzy C-means clustering plots for detection of synchronization

VIII.CONCLUSION AND FUTURE SCOPE

The main conclusions drawn from the presented research work are briefly discussed in this chapter.

Detection ofOperational Events

This research work presents an approach based on S-transform and Fuzzy C-means clustering for the detection of events such as islanding, outage of wind/solar generators and grid synchronization of wind/solar generators inthe DG sources based hybrid power system.

Detection of the Power Quality Disturbances in Hybrid Power System

This research work presents an approach based on S-transform for the detection of power quality disturbances associated with the events such as islanding, outage of wind/solar generators and grid synchronization of wind/solar generators inthe DG sources based hybrid power system.

Future Work

The proposed study has been validated on the IEEE-13 bus test system. To generalize the proposed algorithms, the same study needs to validate on the large test networks such as IEEE-123 bus system.

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