Energy storage and dynamic voltage regulation for plug-in electric automobiles in a power distribution system

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Abstract:

Electric car technology is gaining popularity since it reduces fossil fuel use and ICE pollution. Since an electric vehicle's performance depends on a battery's limited electricity, power flow optimization is vital. Electric vehicles can backup the grid and local loads, lowering peak load and filling the valley point, thus their adoption in the distribution grid is accelerating. Software professionals choose electric cars for their environmental friendliness. Car batteries are connected to grid monitoring facilities for the company's parking garage State of Charging (SOC) charging stations. Renewable power like solar will charge batteries to 100% SOC. Overflow electricity from the PV system can be supplied to the load and grid. The vehicle's batteries will support load at a condition-based Allowable State of Charge (SOC) like a UPS. The day's battery capacity depends on the number of cars on the shift. This study suggests employing the electric vehicle's battery backup as a UPS for a software company and to boost the DVR in the case of a distribution system failure. The EV DVR automatically corrects for voltage harmonics, voltage sag-swell, and distribution system voltage disruptions, increasing the power quality of the entire EV system without additional compensation equipment. MATLAB/SIMULINK models the entire system, proving the goal is achievable.

INTRODUCTION:

The hybrid electric vehicle (HEV) is a promising automotive innovation since it reduces pollution and improves fuel economy. Multilevel inverters increase the performance of high-power HEVs by creating sinusoidal voltages with merely fundamental switching frequency and little electromagnetic interference. Hybrid electric vehicles (HEVs) are more fuel-efficient than conventional cars due to their optimized engines and ability to gather kinetic energy while braking. The plug-in hybrid electric vehicle (PHEV) can drive for 30-60 km on electric power. Electricity from wind, solar, and nuclear sources charges PHEVs overnight. FCVs generate energy from hydrogen, making them practically pollution-free [1]. Through its V2G link to the electric power grid, the FCV can provide backup power during a blackout. Due to hydrogen production and storage issues and fuel cell technology, FCVs are not yet widely available. HEVs may soon dominate high-performance propulsion. Hybrid systems work with most fuels and power sources. Thus, it is not a bridge technology. HEVs and FCVs use electric machines, power electronic converters, batteries, ultra capacitors, sensors, and microcontrollers. Existence of ICE, mechanical, and hydraulic systems does not exclude electrified components or subsystems. Advanced power train components like power electronic converters, electric machines, and energy storage present new challenges in power management, power train system modeling and simulation, hybrid control theory, vehicle control optimization, and component design. At minimum, a large rise in plug-in electric vehicles (PEVs) would require more network power for charging. Overall, the force structure cannot accommodate the increased workload [2]. As more people drive electric cars, interest in charging infrastructure such charging stations in parking garages and covered spaces has grown.

Also, smaller batteries and hence more modest cars are necessary to meet consumer concerns [3] if a charging infrastructure is accessible at the workplace. To accommodate the growing demand for charging systems, it is necessary to meet a few prerequisites beyond the proximity of charging stations, such as as much as feasible and the electrical circuits that enable charging [3]. Charging stations that can manage many vehicles at once with the same technology are one possibility. If many cars are supposed to benefit from a charging station at the same time, then the station's various components need to be shared. Sharing the interface port means safely stopping to different vehicles immediately, sharing the circuit means apportioning the available energy to not over-load the circuit, and sharing as much as possible means acutely booking charging while keeping the end goal in mind to maintain a key distance from peak use. To meet this need, engineers devised a method for charging electric vehicles (EVs) that may safely expand the number of EVs connected to a circuit by dividing the available power among them in a more equitable manner [4].

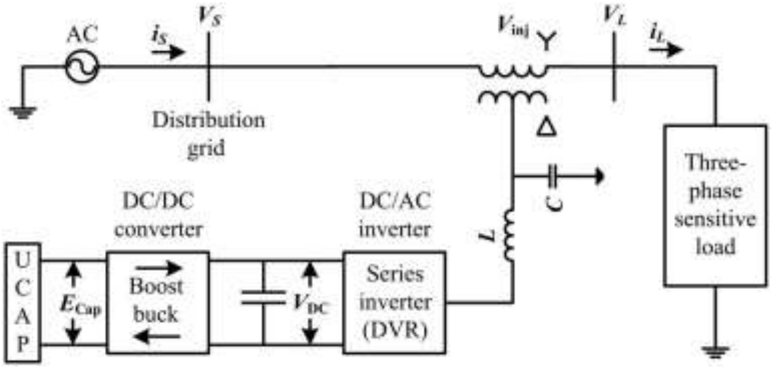

Fig.1. One-line diagram of DVR with UCAP energy storage

PLUG-IN ELECTRIC VEHICLE WITH PV

Sometimes, manufacturers will suggest having a DC/DC battery charger integrated into the dc connection of the PV structure's connection to the grid. The control estimate ensures the PEV battery is charged from the most efficient source by evaluating the power produced by the PV and the power consumption of the PEV. Different scenarios are shown in light of the discrepancy between PV control and the store's demand. The flow of electricity in a PV halting area is managed in the case of by a system of computer-controlled swaps [10]. PEV chargers and the electrical grid are connected through computer-controlled data exchanges, with PV panels of varying ratings serving as the interconnecting medium. The exchanges route all of the power generated by the PV systems to the PEVs, the grid, or both, depending on the available light. Through a series of DC/DC converters, a few PV sheets are connected to the dc transport system.

The DC/DC converter does an excellent job of regulating the power going to the PEVs in light of a few fixed locations of voltage suppression for the dc transport system. In a move that defies common sense, the energy conversion unit powers a three-way flow of vitality between the power system, PV modules, and PEVs. A few manufacturers have presented the idea of DC transport hailing as a means to construct energy to dc stacks for a micro grid. They have likely used this strategy to charge PEVs in a micro grid region more than once.

Since the suggested control figure uses only one parameter—the DC associate voltage—to negotiate the charging station's energy flow, it is easy to understand and implement. It enables plug-in electric vehicle charging with little grid imperativeness and no detrimental effects on the distribution transformer. The next sections explain the feasibility of DC interface voltage recognition and its potential use in the management and administration of PV-controlled charging stations. Several PV string modules connected to independent DC/DC converters that all connect to the same DC bus. In order to power the PV board's operations, the DC/DC converter will track the maximum power point until it is reached. The DC transport is connected to the ESU, or essentiality Energy Storage Unit, through a bidirectional DC/DC buck-help converter. When there is no energy available from the cross section or the PV, the ESU will be used to charge PEVs [11].

After all the PEVs have been charged at the charging office, the ESU's battery pack may be charged from the PV or the lattice. Power for the PEV is supplied by a DC/DC buck converter connected to the dc transport. The control representation shown while charging is dependent on PEV requirements. Each charging station may accommodate a different kind of PEV by providing its own buck converter. A DC-to-AC bidirectional system-tied converter connects the charging office to the power allocation unit. The PEV's power flow from the source is monitored and managed by the control unit. Using the results from the voltage and current identification units, the control unit generates the shifting signals used to regulate the various power converters during charging. In order to implement MPPT, incremental conductance estimate methods are employed to measure the voltage across the PV display and the current leaking from the PV array.

DYNAMIC VOLTAGE RESTORER

Dynamic voltage regulators, series-connected pulse width modulation (PWM) regulators, and static series regulators are all common names for the devices used to regulate the main supply voltage in a circuit. If the device just adds reactive power, then it is a series var compensator. Using the same inverted concept of the supply and load, but this time including a series controller to handle the load. A 0.5pu DVR can restore voltage after a 0.5pu drop thanks to a series device, with the DVR providing just half of the power needed to sustain the load. Similar to a shunt-connected converter, the supply remains connected and no resynchronization is required. The protected load is wired in series with the series voltage controller. While transformers are often used to make the connection, there are some systems that use power electronics to make a coordinated connection. The sum of the grid voltage and the DVR injection voltage equals the voltage at the load bus bar. Reactive power is produced by the converter, while active power is drawn from the energy storage. Each situation calls for a different approach to energy storage to meet the various compensatory needs. Limitations in the depth and length of the voltage sag that can be adjusted by the DVR are a common issue. In order to get the desired certainty, it is necessary to use accurate estimates. Power may be stored in normal capacitors for short periods but at great depth, batteries for longer but smaller voltage dips, or super capacitors that fall somewhere in between. Numerous permutations and configurations are also feasible.

Protection against voltage fluctuations is provided by a dynamic voltage restorer (DVR). DVR maintains the load voltage at a fixed level regardless of the source voltage's irregular characteristics, such as voltage sags/swells or distortion. Figure 1 illustrates the DVR's operating principle. Let Va1, Vb1, and Vc1 be the phasors of the three-phase voltage under normal operating circumstances. During unusual situations, it is possible to change the phase voltage vectors to Va2, Vb2, and Vc2. Unfortunately, DVR does not provide any meaningful power in this unrelenting environment. This implies that in the steady state, the phase angle difference between the voltage and current phasors in a DVR must be 90 degrees. The necessary compensating voltage is introduced by the DVR via transformer. A series connection between the transformer and the load is used. DVR is only active during rare events and does nothing during normal operations. When in use, DVR may both generate and consume active and reactive power.

In the case of a minor failure, a dynamic voltage restorer corrects the load voltage by injecting reactive power generated elsewhere. Active power is produced by DVR when it is needed to correct larger problems. For the active power to be generated, a DC energy device is needed. While conventional systems rely on DC capacitor banks as the dc storage device, the proposed setup makes use of a PV array.

PROPOSED SYSTEM

A. Power Stage

In Fig. 1 we see a simplified schematic representation of the whole setup. Figure 2 depicts the model of the series DVR and its controller, which is used to smooth out the voltage fluctuations that occur when the power stage, a three-phase voltage source inverter, is linked in series with the grid. Isolation transformer, LC filter, and insulated gate bipolar transistor (IGBT) module make up the inverter system. The modulation index m of the inverter is determined by the line-line voltage Vab being 208 V and the dc-link voltage Vdc being 260 V for maximum converter performance.

$$m = \frac{2\sqrt{2}}{\sqrt{3}V_{\mathrm{dc}}*n} V_{ab(\mathrm{rms})}. \qquad (1)$$

where n is the isolation transformer's turns ratio. Using (1), we see that the necessary modulation index is 0.52 if we set n equal to 2.5. For precise voltage correction, the dc-dc converter's output must be controlled at 260 V. The purpose of the active power capacity of the integrated UCAPDVR system is to counteract voltage drops (0.1-0.9 p.u.) and surges (1.1-1.2 p.u.) that continue for 3 seconds to one minute [15].

B. Controller Implementation

Most methods for regulating the series inverter to provide dynamic voltage restoration [3] include injecting a voltage in quadrature with advanced phase. Phase-advanced voltage restoration methods are used primarily to lessen the necessity for active power support and, by extension, the amount of energy storage required at the dc-link, despite the fact that they are difficult to implement. While phase-advanced procedures were once necessary to maintain system voltage during a voltage sag or swell event, the declining cost of energy storage has made them unnecessary. A PLL is employed in the controller to calculate the rotational angle. One of the key goals of the UCAP-DVR system is to compensate for transient voltage drops and spikes using the system's active power capabilities.

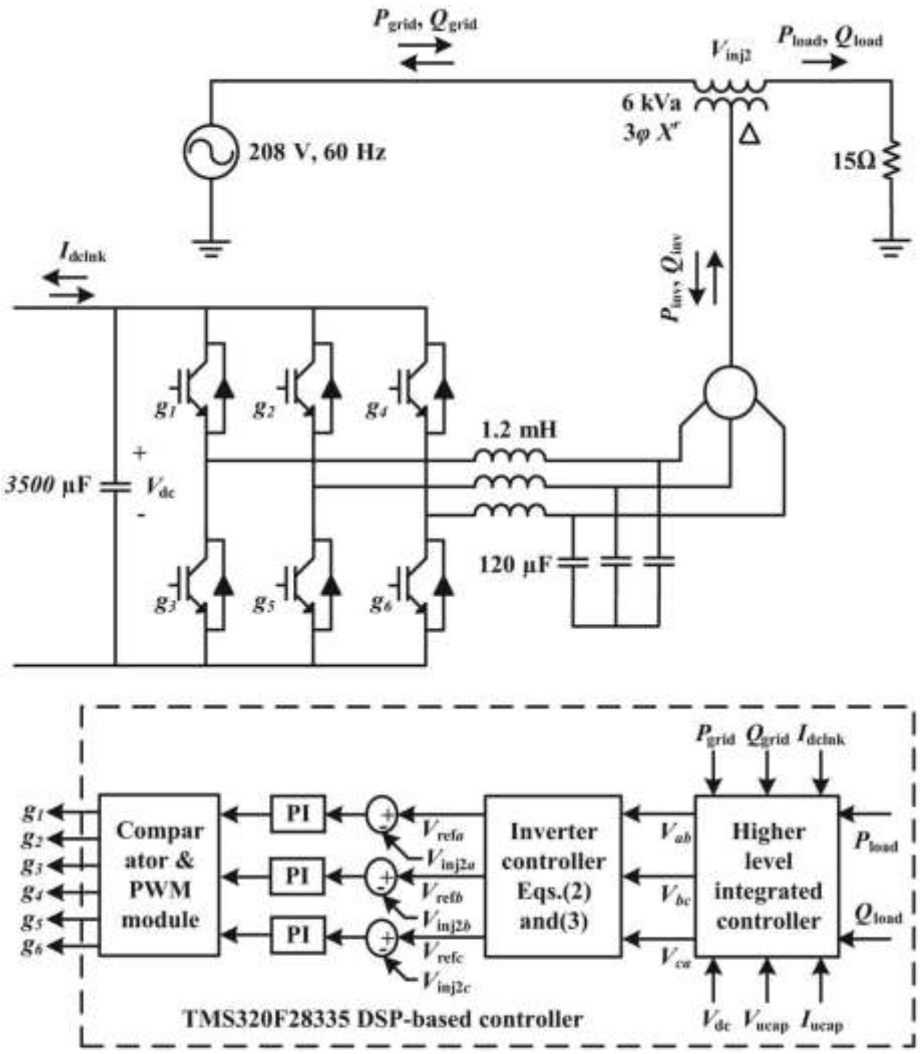

Fig. 2. Three-phase series inverter (DVR) model and controller with integrated HOC

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_q}{\sqrt{3}} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} V_{\mathrm{refa}} \\ V_{\mathrm{refb}} \\ V_{\mathrm{refc}} \end{bmatrix} = m* \begin{bmatrix} (\sin\theta - \frac{V_{sa}}{169.7}) \\ (\sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7}) \\ (\sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7}) \end{bmatrix} \tag{3}$$

$$P_{\mathrm{inv}} = 3V_{\mathrm{inj2}a(\mathrm{rms})} I_{La(\mathrm{rms})} \cos\varphi$$
$$Q_{\mathrm{inv}} = 3V_{\mathrm{inj2}a(\mathrm{rms})} I_{La(\mathrm{rms})} \sin\varphi. \tag{4}$$

DVR and UCAP inject an in-phase voltage Vinj2 whenever the source voltage drops or rises, keeping V_L from oscillating. If we know the injected voltage Vinj2a, the load current

ILa, and the phase difference, we can compute the series inverter's active and reactive power (4).

SIMULATION RESULTS:

These are the findings of a simulation run on the DVR while it is operating in a voltage-sag state, with compensation provided by a Solar-PV/BESS using a VSI topology in the distribution system. There are a number of voltage-related PQ difficulties that might arise when the source voltage is obtained from the grid system at 415V, 50Hz. Specifically, the load voltage effect manifests as a voltage drop between t-0.2 sec and t-0.3 sec. As seen in Fig.4, the DVR's series-VSI kicks on at this point, compensating voltage through injection transformers to keep the load voltage stable.

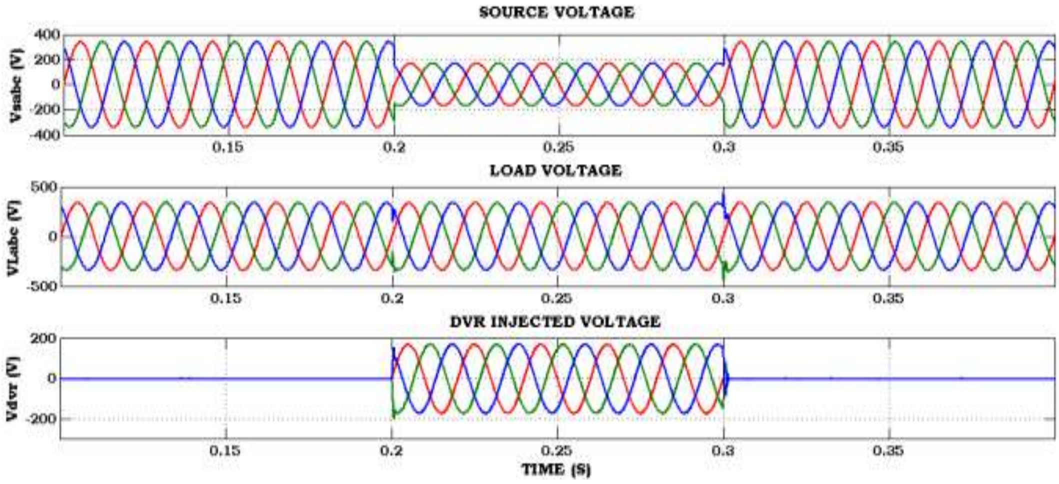

Fig.4 Simulation Results of DVR during Voltage-Sag Condition

We present the results of a simulation of the DVR under a voltage-swell condition, with compensation provided by a Solar-PV/BESS using a VSI topology in the distribution system. There are a number of voltage-related PQ difficulties that might arise when the source voltage is obtained from the grid system at 415V, 50Hz. Load voltage causes a voltage spike at around t-0.4 sec to t-0.5 sec. This triggers the DVR's series VSI, which, as shown in Fig. 5, compensates the voltage via injection transformers and keeps the load voltage stable.

Distribution voltage regulator (DVR) simulation results under voltage-harmonics situation, with compensation provided by Solar-PV/BESS using a VSI architecture. Since the grid system's 415V, 50Hz RMS amounts are subject to a wide range of voltage-related PQ concerns, this is where the source voltage originates. High harmonic distortions in the load voltage are caused by voltage harmonics that develop between t-0.1 sec and t-0.3 sec.

The DVR's series voltage source inductor (VSI) kicks in at this point, correcting the load voltage through injection transformers to keep it sinusoidal, balanced, and constant (as seen in Fig. 6).

Results from a simulation of the DVR under fault conditions that are mitigated by the Solar-PV/BESS and VSI topology in the distribution system. Since the grid system's 415V, 50Hz RMS amounts are subject to a wide range of voltage-related PQ concerns, this is where the source voltage originates. At some point between t0.65 seconds and t0.75 seconds, a fault condition manifested itself, causing the load voltage to drop. As illustrated in Fig.7, the DVR's series-VSI kicks in at this point to keep the load voltage stable by injecting a voltage-reducing current into the load.

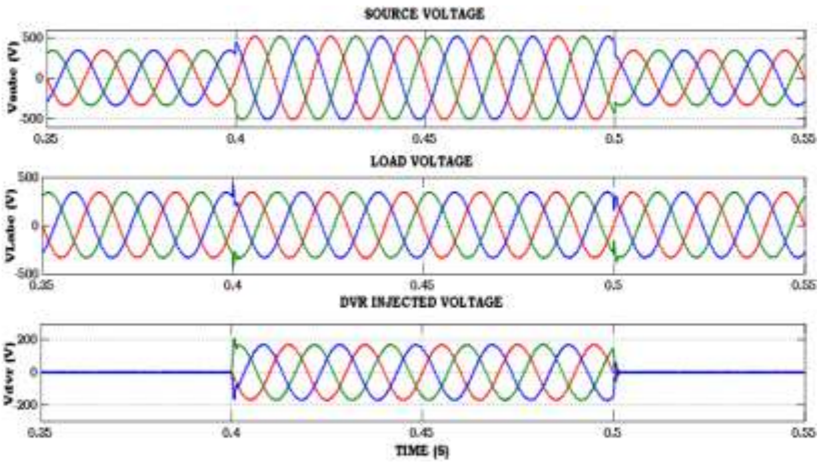

Fig.5 Simulation Results of DVR during Voltage-Swell Condition

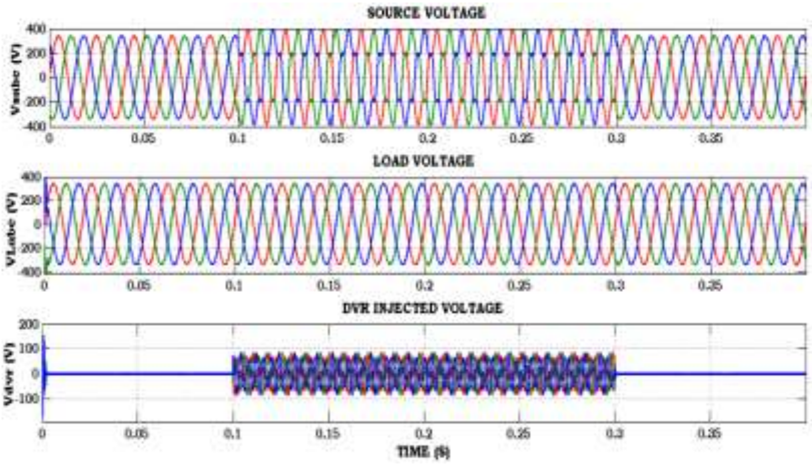

Fig.6 Simulation Results of DVR during Voltage-Harmonics Condition

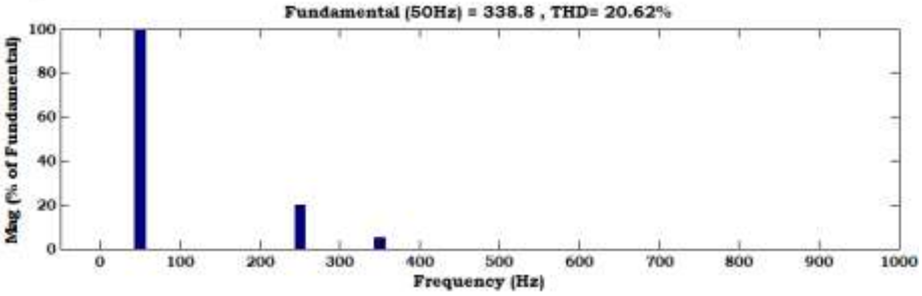

Fig.7 THD of output Voltage

Based on a THD study of the source voltage at 20.62% without compensation and 0.03% with compensation through DVR, the system complies with IEEE-519/1992 requirements (Fig.7).

CONCLUSION

This study presents a power conditioner system using UCAP-based rechargeable energy storage to improve distribution grid power quality. The DVR component can independently handle voltage sags and swells, while the APF component helps the distribution system with active/reactive power assistance and renewable intermittency smoothing. A bidirectional dc-dc converter at the power conditioner's dc-link is suggested for UCAP integration. Shunt inverters (APF) use in-phase compensation, while series inverters (DVR) use idiq. Power stage component designs and operation of the bidirectional dc-dc converter are explored. Since dc-dc converter output voltages are usually steady, average current mode control is employed to fine-tune them. A higher-level integrated controller makes system-parameter-based choices and feeds them to the inverter and dc-dc converter controllers. MATLAB models the bidirectional dc-dc converter, series and shunt inverters, and integrated system of the UCAP-PC system. UCAP-PC can be mimicked with PSCAD. Experimental hardware setup of the integrated system is described, and its capacity to temporarily adjust for voltage sags, provide active/reactive power assistance, and smooth out renewable intermittency in the distribution grid is appraised. Simulations and experiments validate these predictions. Microgrids and low-voltage distribution networks may use UCAP-based energy storages to dynamically adjust to voltage and power demand.

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