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COMMUNICATION CHALLENGES FOR SMART GRID

BY

D.MAHESWARAN, G.CHANDRASHEKAR REDDY

L&T CONSTRUCTION, POWER TRANSMISSION & DISTRIBUTION IC

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SUMMARY

Electric power generation in present time is predominantly based on Non-Renewable resources like Coal, Natural Gas, Oil etc which is leading to an impending global energy crisis due to shortage of the fossil fuels with a combination of uninhibited growth of power requirement world over. The future power generation systems will have to significantly depend on Renewable resources to overcome above crisis as well as to avoid the Climatic change due to Green House effect caused by the waste gases emitted from Fossil fuel based power plants. The above alongwith factors like wide range of power consumers & distribution of them at distant locations from power generating sources makes the power transmission & distribution into a complex system. The recent Northern Grid failure in India during July 2012 which affected almost 600 million people in 21 North Indian states including New Delhi due to a minor trouble at Agra Substation is a good example of the complexity of a national level power grid. This Grid failure also shows how a problem at one location can have a cascading effect on whole grid within no time.

Smart Grid is one of the best solution to prevent blackouts/islanding & bring grid discipline & enable efficient monitoring, control & operation of the geographically distributed gigantic power grid. Smart Grid is the integration of various smart electrical devices at power generation, transmission, distribution & consumers end on a high speed, reliable & secure data communication network to manage the complex power systems intelligently.

Communication networks play a very important role in the efficient operation of the Smart Grid, they have to connect enormous number of electrical devices in the distribution system for to & fro exchange of data messages / commands in a reliable, secure & fast manner.

* L&T Construction, Mount Poonamallee Road, Manapakkam, P.B.No. 979, Chennai-600 089
Fax: +91-44-2270 5482, Tel: +91-44-2270 5001 e-mail: dmaheswaran@lntecc.com

In the last decade very significant developments have happened in the field of data communication & Information Technology systems. A wide choice of communication networks both wired and wireless are now available for selection for use in Smart Grid.

However due to the increasing complexity in the power distribution systems there are various challenges to be foreseen and the most optimum combination of Communication networks have to be selected on the day one to meet the technical requirements like reliability, security, speed, bandwidth as well as other important factors like Scalability, CAPEX (Initial Capital expenditure), OPEX (Operating expenditure), Open platform for easy integration to various third party devices etc.

In this paper we will provide a comprehensive comparison of the various types of communication architectures for Smart Grid with an explanation of the challenges involved in selecting the optimum type of network for various subsystems of the Smart Grid. We will also specifically discuss the network implementation considerations vis-a-vis the functional specifications & physical attributes of various subsystems of the Smart Grid.

KEYWORDS

Smart Grid, Communication Networks, Communication Protocols, Smart Grid Framework.

1. INTRODUCTION

Smart Grid automates the electricity transmission system allowing remote monitoring, automatic protection and optimisation of the operation of various interconnected electrical equipment on the transmission network like power generation, the high-voltage transmission network and the distribution system connecting energy storage facilities, industrial users, domestic consumers including integration with household devices through home automation solution. Smart Grid is characterized as a grid providing two-way flow of power in electrical network linked with a communication network which allows two-way flow of information.

A typical Smart Grid framework showing the interconnection of various subsystems of a power transmission system linked by a communication network is illustrated in Fig. 1 below:

As illustrated in Fig.1, the Smart Grid consists of various domains (generation, transmission, distribution, operation, market, service providers & consumers etc) interconnected via suitable communication networks. Each domain in the grid is required to perform a pre-set functions in a reliable manner to avail the benefits of Smart Grid, i.e. the Smart Control Centers shall monitor and interact with the electric devices remotely in real time, the smart transmission infrastructure shall employ the required control and measurement devices to enhance power quality, the smart substations shall coordinate with their local devices self-consciously.

The system wide automation is feasible only if the data exchange among the various units is fast, reliable and secure.

For each domain a specific type of two-way communication network is to be selected considering criteria like bandwidth requirement, security, initial cost, operating cost and performance requirements.

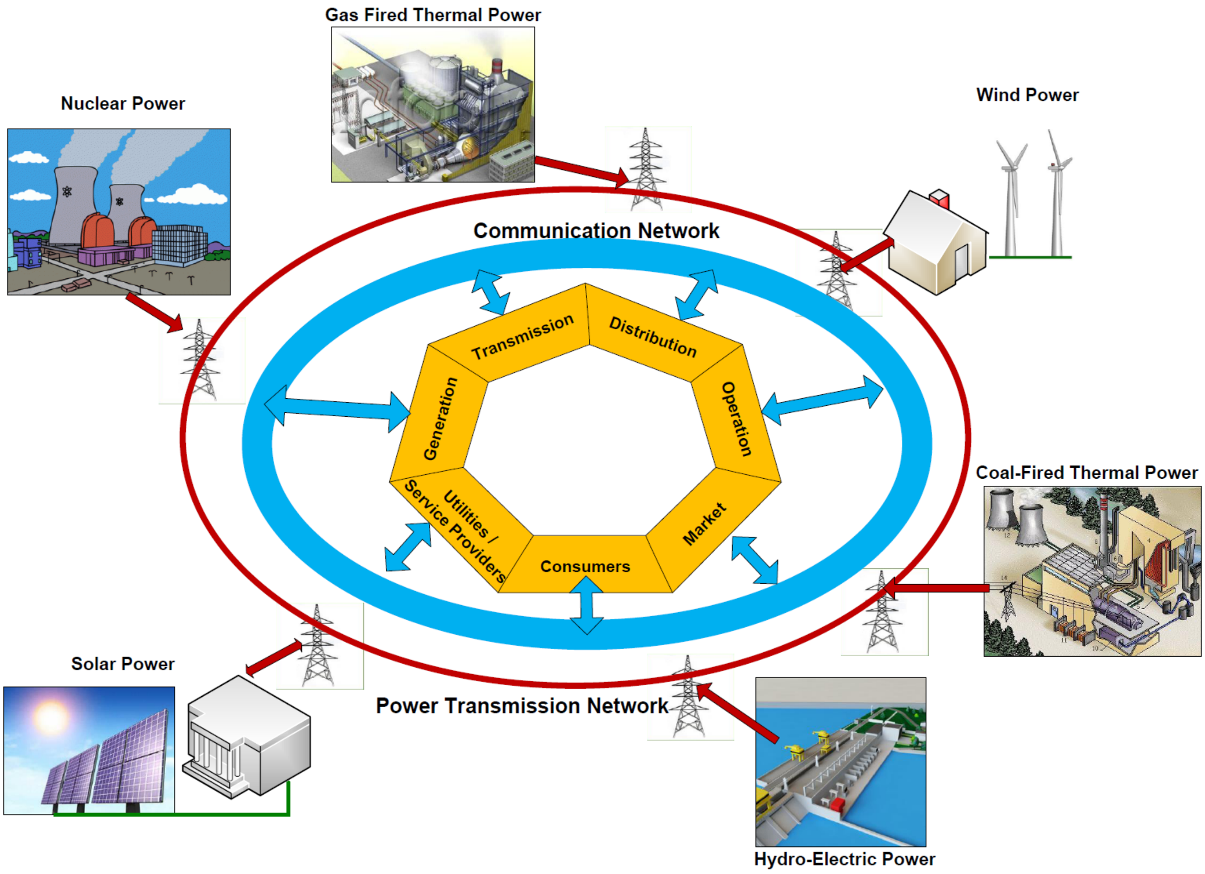

Fig. 1 – Smart Grid Framework – Various domains of Smart Grid

A robust IT solution with reliable and secure communication network will provide the advantages like flexibility, resilience, sustainability, scalability and customisation in the Smart Grid. Communication and IT technologies have gained tremendous sophistication in the recent decades as a separate industry sector.

Modern communication networking technologies now offer a wide variety of options to select from for various subsystems of the Smart Grid to suit the respective system requirements. However still challenges exist in selecting the optimum type of communication media considering the specific requirements of power systems like high speed data communication at adequate bandwidth, data integrity and security, initial cost and operating costs etc.

A detailed analysis of the characteristics of the power systems and the communication scenarios of the specific Smart Grid domain is required to arrive at a practically usable communication network option for the respective domain. Studies have shown that communication networks have several challenges to meet to allow utilisation of full benefits of Smart Grid.

In this paper we have attempted to revisit some of the major challenges in communication networks to meet the Smart Grid application. Under S. No.2, an overview of the basic functional expectations of Smart Grid is indicated, followed by an explanation of various communication architectures & its requirements for Smart Grid under S. No. 3 and under S. No. 4 the challenging issues for Communication networks are explained.

2. SMART GRID FUNCTIONAL EXPECTATIONS

The communication networks provide the platform for the automation and integration of various elements of the Power Systems. A pertinent communication network for the specific subsystem can be selected only after having a better understanding of the expectations of Smart Grid. An overview of the critical functional expectations of Smart Grid is as below:

2.1 Improved Power Quality – Smart Grid is expected to ensure a superior power quality by monitoring and conditioning the power quality at various locations on the Transmission & distribution network. The power quality is automatically maintained as per the load sensitivity. This requirement calls for monitoring of PMU data in realtime at various locations on the grid and taking corrective actions as needed. Communication of the data acquired by distributed PMU's to Smart Grid control centers and the resultant control action back to field will require a reliable, secure, high bandwidth/speed two way communication bus.

2.2 Integration of Diverse Power System elements – Smart Grid is expected to integrate different kinds of bulk power generation, distributed energy resources (Solar, Wind etc), energy storage equipment, Smart meters, PMUs, Electric Vehicle charging stations etc as well as the network shall be compatible for integration of existing conventional equipment. Integration of energy storage equipment and distributed energy resources will allow two way power exchange on the grid. This will allow consumers to sell excess power from his household Solar or Wind power equipment back to the grid. This will call for accurate metering of the two way power exchange and realtime data acquisition and transfer to Smart Grid control center.

2.3 Security – Smart Grid is expected to detect and deter or isolate any breach in security due to physical sabotage on Grid infrastructure or Cyber attack on the IT systems. The Smart Grid shall raise an alarm to concerned operators and ensure speedy recovery from such security breaches. This calls for a high bandwidth communication bus to transfer data from a Physical security system like CCTV or Intrusion detection system to central control centres where any abnormal activities can be detected and suitable alerts are sent on a wireless network like GSM to operators. At the same the communication networks used for the Smart Grid shall have the required security features like Software/Hardware firewalls to allow/restrict only the authorised users.

2.4 Increased Operation Efficiency – The Smart Grid is expected to use the IT technology extensively to analyse the vast information collected across the grid and implement appropriate control strategy to minimise system losses, allow predictive maintenance and improve the efficiency of operation and maintenance of the electric power transmission & distribution.

2.5 Realtime self healing of the Grid – The Smart Grid is expected to detect faults, analyse and take corrective action in real time to automatically heal during any load disturbances and improve the reliability, power quality and efficiency of the grid and minimise Grid failures. Such actions cannot be depended on human intervention considering the very high speed action requirement. This function of Smart Grid poses a major challenge in appropriate Communication network selection.

2.6 Integration of Consumer's Home Devices for Demand Side Management – Demand Response (DR) programs transfer Customer load during periods of High demand to off-peak periods and can reduce critical peak demand or daily peak demand. Shifting daily peak demand flattens the load curve, allowing more electricity to be provided by less expensive base load generation. This will also result in cost saving by avoiding building of additional generation capacity to meet future critical peak demand. Smart Grid allows implementation of Energy conservation programs for ex. the utility can take control of the thermostat of air conditioner in consumer's house and raise it by few degrees during summer to reduce air conditioning load. Providing the benefit of lower tariff to consumer and lower peak demand to Utility. Consumers can have a better access to monitor and avail web based Energy management solutions and increase the efficiency of smart home appliances which can communicate with the grid. A wireless communication typically based on ZigBee protocol may be of use for such home automation needs.

2.7 Web based market opportunities & solutions – The Smart Grid provides a possibility of a lot of new web based services to be offered to the consumers such as capability to buy power through pre-paid plan, buy power from a list of service providers or sell power to different suppliers etc. This feature of Smart Grid calls for an open standards communication platform which integrates users with service providers, suppliers on a web environment in realtime.

2.8 Disaster Recovery System: Smart Grid provides the facility to centrally isolate or restore various sections of the power network. This ability is immensely useful during a natural calamity. During the Super storm Sandy in U.S., the above ability of Smart Grid helped significantly in saving lives and ensured faster restoration of the electric service to customers. The communication network allowed the utility to provide updates and alerts to customers as well as utility's field maintenance personnel. At the same time the utility was able to receive important leads from the customers, in locating & isolating the fault spots on power network for faster restoration. A reliable communication infrastructure is a critical requirement for disaster recovery by the Smart Grid.

3. SMART GRID COMMUNICATION ARCHITECTURES & NETWORK TECHNOLOGIES

Communication networks in a Smart Grid environment can be broadly categorised into Wide Area Networks, Local Area Networks and Home Area Networks a brief overview of these is as below:

3.1 Wide Area Networks (WAN)– Wide area networks form the communication backbone to connect the highly distributed smaller local area networks that serve the power systems at different locations. As Smart Grid control centers are typically located far from the Substations, or the end consumers, the real time measurements done by electric devices on the transmission networks are communicated to control centers through the Wide Area networks. The wide area networks will also convey the control command from control centers back to IEDs (intelligent electric devices) on the transmission network. As the power transmission grid is geographically vastly distributed, the WAN network has to service an unlimited no. of electric devices with huge data communication requirement. Hence this network needs to be based on a high speed and high bandwidth based network.

3.2 Field/Local Area Network (LAN) – This network is typically for the communication requirement of distribution systems. The electrical sensors on the distribution feeders, transformers, IED devices, distribution energy resources, energy storage equipments, electric vehicle charging stations and smart meters at customer premises are services by this network for their data exchange with Distribution Management System (DMS) IT solution at the Smart Grid control centers. This network can be of two types, one network for the field based devices of the distribution system like distribution feeders, transformers, sensors, voltage regulators etc and the other for the customer side integration i.e. for Smart Meters, intelligent home devices of customers houses, industrial users and office buildings etc. The former network is time sensitive and needs to be a reliable and high speed network and later is not time sensitive. This allows the utilities to select different types of communication networks to be selected for either of the LANs. A shared field area network with suitable consideration for real time communication requirements and data security for the Distribution side & a scalable option for the customer side may workout to be a cost effective solution for the utility.

3.3 Home Area Networks – Home area networks are needed in the customer domain to implement monitoring and control of intelligent home appliances, smart meters at customer’s premises and to implement functionalities of Smart Grid like DR (Demand Response) & AMI (Automatic Metering Infrastructure). This network provides a secure two-way communication interface between the utility and the consumer. This network allows Automatic meter reading (AMR) from Smart Meters, display of EMS (Energy Management System) details on customer side display units, load control of customer side intelligent home appliances etc. This network has to be scalable to allow expansion for new customer addition and the same time it should provide a secure communication as important customer data is to be handed by this network. This network could be a combination of wired (Ethernet protocol) or wireless (ZigBee protocol) based.

3.4 Network Technologies – Modern technologies in data communication provide many options to select from for communication requirements of Smart Grid. However a single technology may not be suit all the applications of the Smart Grid. A best fit technology or a subset of technologies may have to be chosen for a group of power system applications to meet the Smart Grid functionalities. Before a technology is selected a thorough analysis is mandatory to ensure that the application requirements are met by the technology selected. International Electrotechnical Commission (IEC) proposed a number of standards on communication network design for power systems for ex. IEC 60870, IEC 61850, IEC 61968, IEC 61970, IEC 62351 etc. Similarly a number of standards are proposed by IEEE also.

The currently available communication technologies in the market can be broadly classified under following headings:

3.4.1 Power Line Communication – This technology uses the electrical power transmission lines for data transmission by superimposing a modulated carrier signal on the power transmission wires. However the constraint in this technology is that data signals cannot travel through transformers and hence the power line communication is limited within transmission line segment between transformers. Data rates on power lines can vary from a few hundred bps (bits per second) to MBPS (Mega Bits Per Second), inversely reduced by the distance of the power line. In view of above power line communication has restricted utilisation on the main transmission network and not usable on the distribution network.

3.4.2 Wired Networks – Dedicated copper or optical cables are used to form Wired Networks for data communication. These networks require extra initial investment however they offer a secure, reliable, high speed and high bandwidth communication network. Wireline communications use protocols like SONET/SDH or Ethernet on fibre optic media and are capable of providing high speed data communication ranging from 100MBPS to 160GPBS. Ethernet is an open and widely used protocol and several OEMs (Original Equipment Manufacturers) have electrical devices compatible with Ethernet. DSL (Digital subscriber line) provided by local telephone company and the Coaxial cables can also be used a wired copper networks which can provide upto 10MBPS.

3.4.3 Wireless Networks – Recent advancements in Wireless Communication Technologies has enabled interfacing of the devices on a communication network without laying any wires. Wireless communication technologies are best suited for the AMI, Home Area network application which need good scalability and data rates are lower. Wireless communication is constrained by transmission attenuation and environment interference and statutory regulations. As a result wireless communications can be deployed for short haul connections with comparatively low data rates. Wifi networks based on IEEE 802.11 are used as local area wireless networks and can provide data rates upto 150MBPS upto a maximum distance of 250m using license free frequency spectrum like 2.4 GHz. IEC 14543 provides the details of communications protocol tailored for short data packets produced by wireless devices that function with a minimal amount of energy specifically for home area networks.Higher data rates upto 100MBPS and long haul wireless communication i.e. upto 50KM is possible using licenced frequencies allocated by statutory Government agencies (WPC – Wireless Planning & Coordination wing of Ministry of Communications in India) against a recurring annual royalty.

Latest communication technologies like GSM, GPRS, 3G & 4G offer good economic alternative wireless communication networks which incur Nil initial costs as the infrastructure is already established and maintained by telecom service providers, however a recurring cost based on usage is applicable. These technologies are ideally suited for AMR and DR functionalities as well as for data collection from remote inaccessible meters/IEDs which is not time sensitive.

4.0 COMMUNICATION NETWORK CHALLENGES TO MEET SMART GRID FUNCTIONAL REQUIREMENTS

Communication network is a vital component of Smart Grid as it performs the important function of data exchange among various subsystems of the grid. A wrong selection or under-performing communication network not only limits the Smart Grid from performing its intended functionalities (Refer S. No. 2), it can seriously damage the electric grid. In order to ensure that Smart Grid meets it optimal performance, the communication network has to be selected based on a number of criteria as indicated below:

4.1 Network Latency – Network latency is defined as the maximum time in which a particular data reaches its destination through a communication network. The data communication between various subsystems of the electric grid may have different network latency requirements. For example the protection information and control commands between IEDs (Intelligent Electric Device) in a transmission/distribution grid will require the lowest possible latency than the data acquisition which is only for monitoring purpose. If the network architecture has multiple hops due to geographical constraints and distance limitation of the network hardware selected, latency of the data may directly get increased. The bandwidth of the communication network will also dictate the latency of the data transfer from one entity to the other.

Timing of data/event communication is critical in Smart Grid. Certain types of events communication between IEDs has significance only if it is done within a predefined time frame. If the communication delay exceeds the required time window, the transfer of data does not serve any purpose as the damage might have already incurred in the Grid. For ex. circuit breaker operation when the voltage or current exceeds it set limits usually has to operate within a small time window of 3ms inorder to ensure Grid stability.

IEEE & IEC define rigorous communication delay requirements in Smart Grid for different type of information exchanges. These timings must be satisfied when selecting and implementing the communication network infrastructure for the Smart Grid. Communication network technologies developed in the telecom industry have been designed to the performance requirements of IT industry and not designed to meet the stringent delay performance requirements of Smart Grid. Hence a careful selection of the appropriate media and protocol is required to meet the stringent communication delay requirements of Smart Grid.

The typical communication timing requirements specified under IEEE 1646 for Substation Automation are shown in table1 below:

Table 1 – IEEE1646 Standard: Communication timing requirements for electric substation automation

Information Types	Internal to Substation	External to substation
Protection Information	4 ms (1/4 cycle of electrical wave)	8-12ms
Monitoring & control information	16 ms	1 s
Operations & maintenance information	1 s	10 s
Text Strings	2 s	10 s
Processed data files	10 s	30 s
Program files	1 min	10 min
Image files	10 s	1 min
Audio & Video data streams	1 s	1 s

Table2 – IEC 61850 Communication networks and systems in substations: communication requirements for functions and device models

Message Types	Definitions	Delay requirements
Type 1	Messages requiring immediate actions at receiving IEDS	1A: 3ms to 10ms; 1B:20ms or 100ms
Type 2	Messages requiring medium transmission speed	100ms
Type 3	Messages for slow speed auto-control functions	500ms
Type 4	Continuous data streams from IEDs	3ms or 10ms
Type 5	Large file transfers	1000 ms (not strict)
Type 6	Time Synchronisation messages	No specific requirement
Type 7	Command messages with access control	Equivalent to Typ1 or Type 3.

4.2 Data Integrity – The protocols selected for a particular power system application must provide the required data integrity depending on the criticality of the application. Certain applications will need high integrity where an end to end delivery must be confirmed and its absence shall be followed by a retrial. For example control commands for positioning of electrical switchgears. Above applications can be configured with high priority over others like data communication of monitoring data from measured current, voltage sensors, where data loss can be detected by the receiver but a confirmation is not required at the other end.

4.3 Reliability – The Smart Grid maintains the grid stability and various functions of the grid by communicating critical data over the Communication network. Hence it is extremely important to have a high reliability communication network for a successful and efficient power grid. The reliability of the communication network is dependent on a no. of causes like time out failures, hardware failures, software failures, end IED device failure etc. Time out failure occurs if the time spent on detecting, assembling, delivering the data and taking action exceeds the timing requirements. Hardware failures and software failures can be overcome by going for suitable redundancies in the network hardwares when the communication network is handling critical power system applications. Noise and interference in the physical medium can also lead to network failures. The communication network's reliability has to be assessed during the design stage to ensure the network is designed and implemented with the required reliability to avoid compromising of the reliability of the Smart Grid.

4.4 Security – Smart Grid utilises various types of communication networks like Wide Area Network, Local Area Network, Home Area networks based on the specific needs of the Power System application. As these networks are spread over considerably large geographical areas cyber security from hackers is vital. Due to the inherent requirement of Smart Grid application, some of the devices may need to be connected on a wireless communication network and there is also a need to interface with Internet Service Providers for providing web based solutions to consumers, utilities and power suppliers. These are the most susceptible points for hacking leading to compromise in data security. Security protection can be enhanced by use of suitable fire walls (hardware/software) and authorised access to realtime data and control functions in the network at susceptible locations on the network. Use of encryption algorithms for wide area communications can prevent spoofing. IEC 62351 addresses the cyber security requirements of the IEC protocols.

4.5 Time Stamping of Data & Time Synchronisation – Time synchronisation of devices on the power grid is needed to ensure timely operation of protection mechanism. Time stamped data allows a chronological analysis of faults and disturbances to select the optimum control and protection strategy in the SCADA. Tolerance and resolution requirements of the time synchronisation are strict for IEDs (Intelligent Electric Device) that process time sensitive data & involve in control and protection mechanism. For example, time stamping of data measured by PMU (Phaser Measurement Units) is required at very good resolution as it provides a real time measurement of electrical parameters at various locations on the grid for analysis of flow of disturbances and allow selection of an appropriate corrective action. Time synchronisation of the communication network as well as the IEDs can be achieved through a variety of protocols and master references like GPS Master clock. Precision time protocol (PTP) defined by IEEE 1588 provides time synchronisation upto nanosecond precision. SNTP (Simple Time Network Protocol) is another way of achieving time synchronisation for substation automation and same is described in IEC 61850. IEC 61588 provides details of Precision clock synchronization protocol for networked measurement and control systems.

4.6 Multicasting of Data – Multicast of data is crucial in a Smart Grid power system application as the single data originated from an IED /measurement sensor is required by several IEDs and IT Application servers simultaneously for different functional requirement. The communication network and protocols selected should allow multicasting of data, i.e. instead of multiple individually addressed messages, a single multicast data message can be sent on the network which is forwarded to all outgoing ports of the network. The receiving devices are simply configured to retrieve the particular multicast address useful to it.

5.0 CONCLUSION

Smart Grid is the best solution to take care of the global energy crisis by integrating renewable energy resources and making the existing grid more efficient and optimum. Communication network is an indispensable component of the Smart Grid and a careful design and selection of this component is very important to derive the best performance from Smart Grid. Several challenges as explained in this paper are to be foreseen and an appropriate communication topology, protocol, media is required to be selected for an effective Smart Grid.

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