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Software System Architecture of Power Grid with IPMI Approach – A Demand Aware Smart Grid

Ramesh Ananthavijayan[1], Prabhakar Karthikeyan Shanmugam[2], Rangarajan Varadan[3]
[1]Head of Engineering, Robert BOSCH Engg& Business Solutions Ltd,Coimbatore, INDIA
ramesh.ananthan@gmail.com
[2]SELECT, VIT, Vellore, INDIA
spk25in@yahoo.co.in,
[3]Software Project Leader, APTIV Services GmbH;
Munich Bavaria Germany
rangarajan.varadan@gmail.com

ABSTRACT
The work – IPMI based protocol for smart grid architecture (named as SGMPI) aims to define and develop a Software System Architecture (SSA) for power grid electronics. The ability of the electronics to communicate with each other and use feedback makes the Power Grid a Smart Grid. The software system running on the embedded electronics in the power grid, reside at the various generating sources, substations and distribution points. The huge volume of data collected from these points, has to be managed and the methodology of data server architecture is a promising solution. Smart grid architecture demands remote-data monitoring and robust data exchange. IPMI based architecture is capable of handling the large amounts of static data and short bursts of dynamic data in the grid. Proposed architectural solution is described in "4+1 architectural model" and arrive a detailed architectural viewpoint. The methodology of deriving IPMI architecture for smart grid is explained. In short, new data oriented software architecture for smart grid system is explored.

Key words: Software architecture, Intelligent Platform Management Interface, Data acquisition, Smart meter, Server & Client, architecture viewpoints.

1. INTRODUCTION

Smart Grid a multi-dimensional research field in which the traditional power generation, transmission and distribution mechanisms have to assimilate with modern electronics (sensors, actuators etc...) and software technologies. The information and communication technology enable the power grid to become Smart Grid with interfacing the grid components and exchanging data. The device intelligent and the data volume are exponentially expanding and technology is continuously upgrading in a faster way. Moreover the sheer volume of data, generated from huge number of information sources imposes technological complexities.

ISO/IEC/IEEE 42010 defines software architecture as "a fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution". The IEEE 1547 recognizes the interactive nature of the interconnection with the grid and all of its parts, and realizes the significance of the integration of power, communications, and information technologies into the smart grid [1] [2]. Smart Grid architecture is compared with the internet, a loosely coupled system of system and composites of many system and subsystem architectures developed independently. The interface and data flow requirements defines the structure of smart grid architecture [4].

The core objective of smart grid is to ensure seamless electricity supply by meeting dynamic and distinct requirement of diverse customers. The grid is not only to be robust enough to integrate modern electronics in generation and transmission systems, but also to cope up with supply chain and data handling techniques. The business demand is to provide seamless environment in which producers and consumers come together and exchange of electricity, data and money.

The technology transformation of power grid to smart grid enables to install and integrate sub-systems such as Generation, Transmission, Distribution, Utilization sub-systems. The methodology of smart grid architectural representation is researched in [4] [9]. The architecture also enables the stakeholders like producer, consumer, and service provider to exchange the information. Such an architecture integrated with cloud systems (weather prediction data, cost of power) increases the competitiveness amongst service and power providers. The increasing number of grid stakeholders demands a stable, reliable and expandable platform that meets power requirement, data exchange and technology up gradation opportunity.

Smart grid system organization and integration contributes to solve many of above listed problems. The visualization of several smart grid technologies is a complex problem and poses challenges to configure, monitor, maintain and control energy equipment. Smart grid is viewed as software intensive system in which majority of devices / components contain electronics and software [3]. IEEE 1471 describes, Software-intensive systems are those complex systems where software contributes essential influences to the design, construction, deployment and evolution of the system as a whole [11]. Smart grid software architecture is characterized as large scale, multi-disciplinary, highly interconnected, data driven system. The core fundamentals of Smart-Grid and power management systems pertain to reliability and definitive control over the power grid equipment, thus the architecture focuses on the security aspects aswell. Cross domain technology applications in power grid creates great potential to realize smart grid requirements.

Why IPMI?

Intelligent Platform Management Interface (IPMI) protocol is commonly applied to manage and monitor highly interconnected data server systems [8]. IPMI relies on a byte level protocol which provides for requests and responses, the device sitting in the remote location always acts as a server. We propose a byte level communication based software architecture for smart grid. The smart grid is analogous to data centres/servers, except for the sheer volume of the data travelling in and out.

The obvious feature of the smart grid is it has two-way flow, i.e. information flow and power flow. The information flow is planned to be implemented by the IPMI communication technologies in the smart grid networks. The data collection and exchange among consumer, energy sources, distributors and cloud systems decide the basic structure of smart grid architecture.Rest of the paper is organized as follows:

The communication architecture of smart grid is focused and explored cross domain application of data server technology. Section 2 elaborates on the necessity of novel methods of smart grid data handling and connects with IPMI techniques. The conceptual model of IPMI basic architecture is depicted in Section 3. The architectural viewpoints are described with standard architectural view model. Section 4 focuses on the implementation aspects of architecture along with all grid subsystems parameters. The conclusion and future focus is briefed in Section 5.

2. MODERN POWER GRID ARCHITECTURE

2.1 Paradigm Shift of Power grid to Smart Grid

Conventional power grids face challenges in terms of handling more generation resources, interfacing with modern electronics and managing dynamic customer requirements. In the next-generation, electric power systems that incorporate diversified renewable energy resources, automated and intelligent management are the critical component that determines the effectiveness and efficiency of power systems. In a typical power grid environment, the quantity of monitoring data exceeds the control and monitoring data by a significant factor. This demands high number of data acquisition devices in smart grid [6].

The smart grid technology as represented in figure1 integrates the modern digitization, cloud and communication techniques by offering flexibility, resilience, sustainability, and customization. Salient features are listed as follows:

- Monitor and interact the electric devices remotely in real time
- Smart transmission infrastructures to enhance the power quality
- Smart substations coordinate with their local devices self-consciously
- Ability to realize data interface requirements

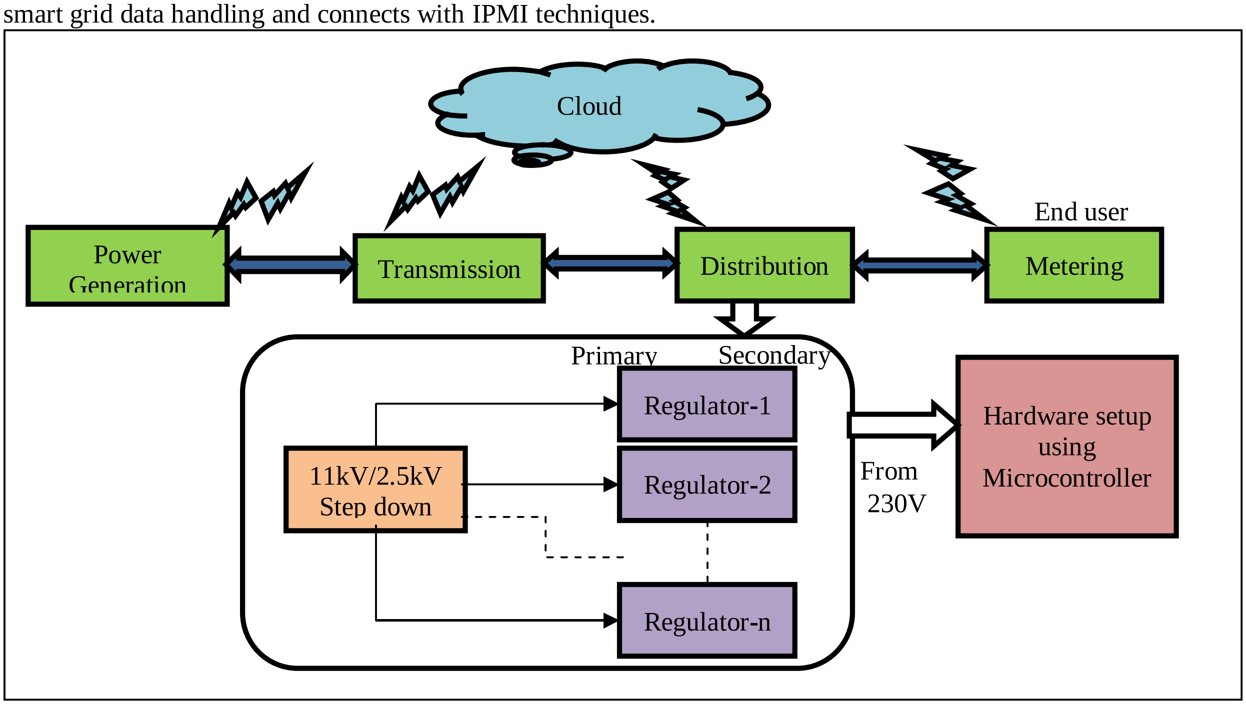

Figure 1: Communication flow in Smart Grid

Smart grid technology brings significant advancements in system automation and intelligence. With such technology transformation journey, the concept of energy internet has been proposed that envisions an exciting prospect of the future energy utilization paradigm throughout all the energy generation, transmission, and distribution and storage phases.

A smart grid often replaces analog mechanical meters with digital meters that record usage in real time. These smart meters, the key component of a smart grid, records consumption of electric energy in intervals of an hour or less and enables two-way communication between the meter and the central system [19]. The high volume of metering data (voltage, current, active and reactive power consumption and generation) at every customer connection point can be used for alerting distribution system operators for power failures or exceeded permissible power quality limits.

2.2 Conceptual foundations: Why IPMI?

IPMI is a set of computer interface specifications for an autonomous computer subsystem that provides management and monitoring capabilities independently of the host systems CPU, firmware and operating system [7]. In a typical data server architecture, System admin can use IPMI messaging to monitor platform status such as temperature, voltage etc. ,to query inventory information, to review hardware logs of out-of-range condition or to perform recovery procedures such as issuing requests from a remote console through the same connection. IPMI allows for sensors that are integrated in current generation server hardware to be accessed over a common API [18].

The limitations of agent based architecture [5] and others makes it essential for a new software architecture for smart grid which will monitor, control and maintain the entire system firmware. IPMI concept till now was considered in server domain, but so as to develop system architecture, it is to be brought into the smart grid domain concept. The transactions are requests and responses, requests are often broken in to subcommands, unique and relevant responses are designed in the Protocol.

A typical smart grid system is similar to a datacenter system, where the devices sit in a remote location and provide a means for a Supervisor or Administrator to access the system remotely. The remote access happens over a secure connection and also will need reliable data transfer. Hence it requires a light and fast protocol definition, which is the highlighting part. Datacenters consists of servers, routers, switches and hubs, all capable of intercommunicating with each other and communicating to the outside world to adhere IPMI Protocol. Till now no communication architecture has been developed so as to have communication with smart grid and to have communication between the electronics. The feedback mechanism in the smart grid helps conserve energy.

The Use of IPMI as a reference for the smart grid software system architecture (henceforth referred as SGPMI) is driven by few key reasons:

- IPMI is simple and uses a light protocol
- IPMI works on a Medium High Security like SSH or HTTP(s)
- IPMI is highly interoperable with mostly interchangeable hardware
- IPMI standards adhere to ISO-OSI Model

2.3 Comparative Analysis

SCADA & DNP3 systems are conventionally popular in power gird environment. A comparative analysis with SGPMI protocol was done and results are summarized in Table 1.

Table 1: Comparison of SGPMI protocol with SCADA & DNP3

Feature	SCADA	DNP3	SGPMI (based on IPMI)
Medium	Serial	Serial (UART, FIBER, Ethernet)	Ethernet (TCP/IP)
Number of Layer	N/A	Layer 2	>Layer 4
Time Synchronization	With Special RTU not in N/W	With and RTU	With Time Service
Time Sequenced Data	Stored	Stored	Stored and Instantaneous
Data Rate	Serial Baud	AFA 100 Mb to 1 Gbps	6 Gbps or higher
Event Monitoring	Via DNP-RTU	Via RTU	Real Time Event Monitoring
Scalability	Intra-scalable (within a subsystem)	Inter-scalable (Between Subsystems)	Ultra-scalable (Between Super Systems).
Floating Point Data	Integer Scaled	Integer Scaled	Float, Long (any new Datatype easy to implement)
Payload Length	Limited by Protocol Bitness	Limited by Bitness (Higher than SCADA)	High PL, of the order of GBs.
Types of Equipment	Limited to Industry and	Limited to Industry,	Interoperable between any

	Implementation	Implementation, but expandable within a domain (SG)	domain, hence easy integration in to Cloud Services
Demand Awareness	N/A	Sparingly Pre-Configured	Can be Completely Demand aware
Expansion in to Related areas example: Video Monitoring	Not Possible	Possible with Major Overhaul	Possible with base minimal implementation
Cybersecurity	Uses old Techniques, High Vulnerability	Uses Documented Techniques, Medium to High Vulnerability	Uses State of the Art Techniques, Continuous reduction of Threats and Vulnerability

3. CONCEPTUAL MODEL OF ARCHITECTURAL DESCRIPTION

The key conceptual foundation for this SG-SSA (Software System Architecture) is the IPMI 2.0, it is defined to work over an I^2C bus internally within a system board/chassis (within the server), but uses TCP/IP over SSH & HTTPS methods to communicate with remote clients as shown in figure 2. The embedded systems in datacenters provide a backdoor entry in to the system and are able to monitor, configure, update & maintain the systems they are physically attached to. This increases availability and reliability of the system and in turn the entire datacenter. The SG-SSA can use any such board level communication mechanism such as UART, SPI etc., Like the datacenter, power grid architecture calls for each device to act as a Server & Client at times.

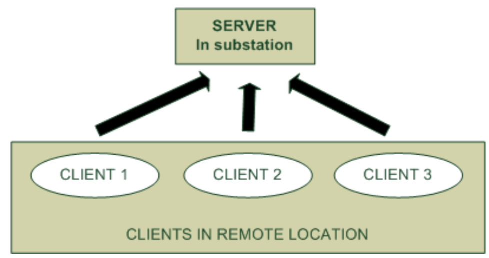

Figure 2: Block Diagram of the Server-Client the Concept

3.1 Basic Architecture of IPMI based Systems:

The communication between the embedded management systems is defined by the open hardware management (as refered in figure.3) interface specification similar to Intelligent Platform Management Interface (IPMI). Baseboard Management Controller (BMC) will take care of the monitoring and controlling of devices within the system & within the Datacenter [10].

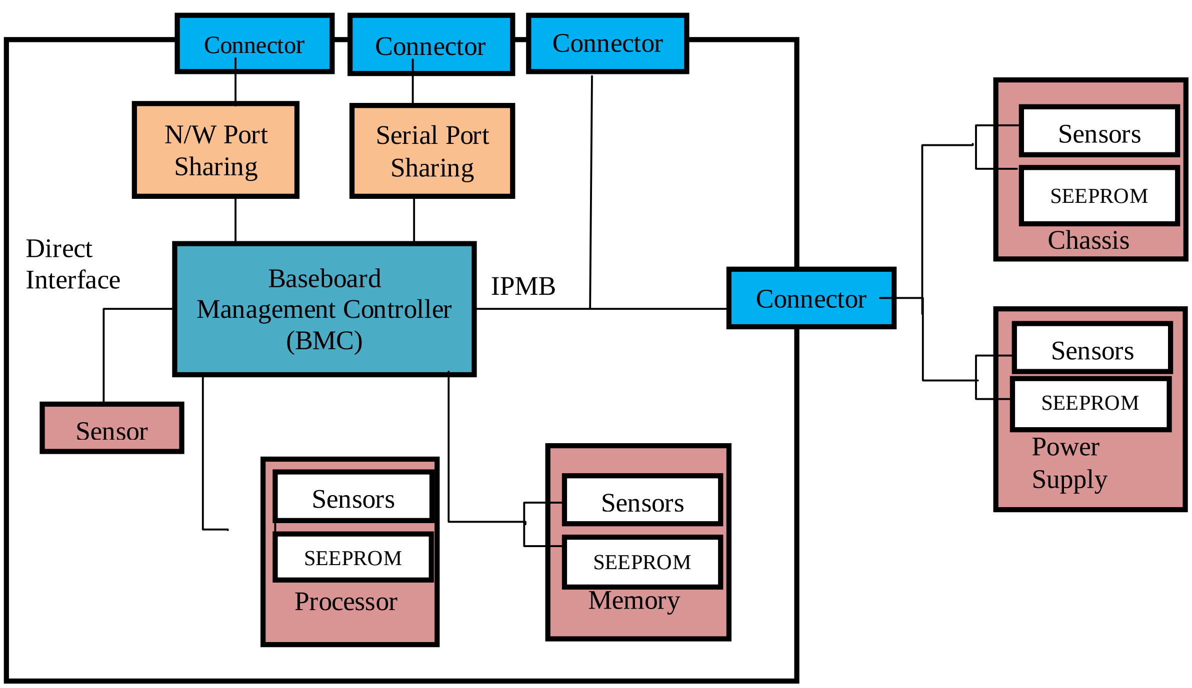

Figure 3: IPMI Architecture Description

IPMI bus enables the communication between host OS and other IPMI aware devices. The access from host OS will be routed through BMC. Thus the one who depends on BMC, which is the heart of IPMI is called as satellite controllers. BMC will send and handle events.

3.2 Architecture Description

Using the IPMI 2.0 as the base reference, the architecture so defined in this document is meant to portray all properties and uniqueness of IPMI [7]. Additionally, the smart grid software architecture shall emulate the IPMI (only in Software) over an energy information transmission hardware platform such as Serial or Fiber-Optic. The objective is going to be able to achieve the most important feature of an electric smart grid, which is reliability [12].

Software architecture is entirely based on the protocol that is to be formulated from the data points obtained from the datasheet of different equipment and devices used in the substations. Several such data points are gathered and grouped and enlisted in APPENDIX A.

Instantaneous values of voltage, current etc. are examples of the data points considered. Metering, control, protection and communication are the main categories considered for data point classification. Upon considering different case studies, the concept shall fit into existing substation infrastructure. The end user distribution and the user management are also addressed by IPMI architecture.

- Meter control
- Meter reading management
- Data management
- Fault monitoring & Protection
- Data integrity
- Device management - addition, rights management
- Privacy management
- Identifiers:
  User ID, email addresses, telephone numbers, URI and IP addresses, and others.
- Credentials: Digital certificates, tokens and biometrics, and others.
- Attributes: Roles, claims, privileges, patterns and location, and others.

The Protocol itself is designed with byte pattern based command structure.

3.3 Architecture viewpoints:

Acommon practice in software architecture design is to apply architectural views to model the design decisions for the various stakeholder concerns .The smart grid architecture is visualized and described with architectural viewpoints to realize the indented features [13], [14], [15], [16].

Functional View Point: The most fundamental functional elements of smart grid software architecture based on IPMI, are the data points, which are basically the smallest retrievable elements from the substation/ generation / distribution electronics. They could be grouped together and retrieved as a set of information.

Information View Point: The significant the proposed software architecture lies largely in the way it handles information. The architecture tailors the information handling, firstly in to simple commands asper the IPMI Architecture. The Information is then packetized in ways where it can be transmitted as one single data point or a group of data related points. Since the smart grid involves large amounts of static data, and short bursts of dynamic data, the expectation of the information view point from the proposed software architecture, shall be the data itself, and the handling of static or dynamic data shall be the same.

IPMI standards have lately adapted to a FQDD: Fully Qualified Device Descriptor model of data exchange/Information handling, which standardizes the way a piece of information or a set of data is retrieved from the various nodes of the smart grid. This kind of device descriptor based information view point allows easy development, scalability and maintenance life cycles on the software development, while the maintenance & sustenance are also made easy.

Concurrency View Point: The proposed software architecture, shall in each of its implementation utilize the services of a robust but simple (Round Robin or Co-operative) real rime operating system. The need for concurrency shall be rare and the system design shall be event driven.

A typical example shall be a power generation event in process shall take priority over a metering information request via a remote connection (cloud).Concurrency viewpoints shall also create a comprehensive inter-process communication, essentially creating layers of software, such as the core hardware level driver layer, which is supported by a unique data management layer (refer figure 4). The data management layer could use a service request and response method of responding to various clients which request for information. The clients projected here are Software layers which work their way from user interfaces down to the data management layer.

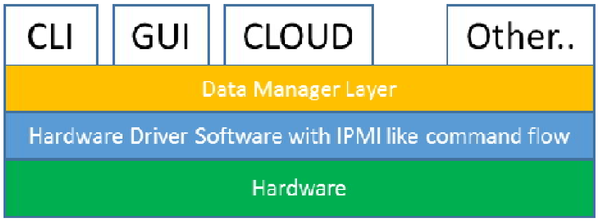

Figure 4: Software layers to assist Concurrency Architectural viewpoints.

Development View Points: The fundamental contributing factor to the ease of the proposed software architectures development viewpoints is the information viewpoints. Development with the above mentioned software architecture shall typically and fully be supportive of an agile software development methodology.

Deployment View Points: The embedded systems which shall host the software carrying the proposed software architecture shall be resourceful microcontroller systems. The significant difference in the proposed architecture Vs the data canter IPMI, shall be in the bus on which the protocol shall be implemented. In the IPMI case it is largely implemented on I2C bus. Due to the poor noise immunity of the I2C bus, it shall not be the bus used primarily in the Smart grid.The various substations in a smart grid are prone to heavy magnetic fields and fluctuations due to open weather conditions, also in nuclear power plants the radiations shall also add significant noise and communication disruptions to I2C. Hence the ideal bus for the Smart Grid software system, as it is today is serial over fiber optic. The communication network shall be a typical many to one connection, the communication shall be based on addressed one to one communication. All remote logins shall contain a secure login mechanism, over an encrypted medium.

Operational View Points:
Installation of the smart grid embedded systems shall involve the OEMs deploying their subsystems infrastructure; the embedded systems which host the proposed software architecture shall contain microcontroller systems containing preprogramed software that shall adhere to the proposed architectures command level protocol. These are the modular parts of the IPMI software architecture which this proposed Smart Grid software architecture for chooses to reuse.

Architecture view
The proposed software architecture (figure 5) for the Smart Grids shall choose the 4+1 view model designed by Philippe Crichton [15].

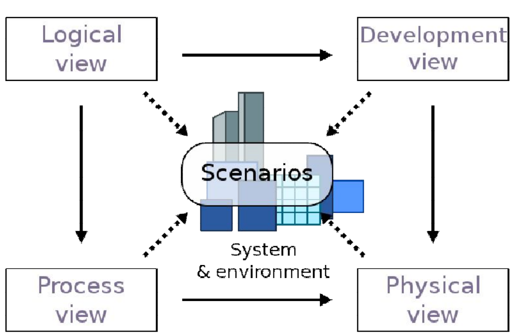

Figure 5: Philippe Kruchten 4+1 view model:

Logical View: The logical view w.r.t the proposed software architecture provides the end users, a secure, reliable, simple mechanism to handle information. The fundamental functionalities of reading, writing, maintaining and sustaining these smart grid embedded systems is achieved using the device descriptor based data handling technique, like the IPMI.

Reading information from the embedded systems involves retrieving one small piece of information such as current load voltage or current. The retrieving can also be the entire metering data set (primary voltage, primary current, load voltage, load current, power and power factor).

Writing information into the Embedded Systems involves, for instance, configuring the secondary output percentage based on the demand i.e. when demand is high, in the mornings and evenings, the secondary could boost the load voltage to 110% while during the day when demand is low, the secondary could ramp down to 90%. The configurable parameters being, based on the particular residential locality, the time of day, for demand awareness and the amount of voltage to increase or decrease for that period of time.

Maintaining: The substation embedded systems will require maintenance in the form of firmware upgrades, security upgrades etc. Additionally, the substation hardware such as transformers, voltage regulators [17], three phase regulators, power generation turbines and so on.

Sustenance: Sustenance of the software architecture shall pertain to saving information related to power generation, transmission, distribution and consumption. The data so recorded shall help you all in future generations of the products carrying the same architecture to evolve using the data collected.

4. IMPLEMENTATION OF IPMI ARCHITECTURE IN SMART GRID

Authors are researching the practical implementation of IPMI protocol in power grid network. The miniaturized grid is conceptualized and being implemented as shown in figure 6 with IPMI protocol architecture. One of the most important applications of proposed IPMI based smart grid system is to be able to collect data from the generation source, transmission line, distribution substation and the consumer. The data collected from various sources are shared with substation and consumers to manage the power and status of transmission. One more feature of our system is the ability to control load and transmission line from anywhere.

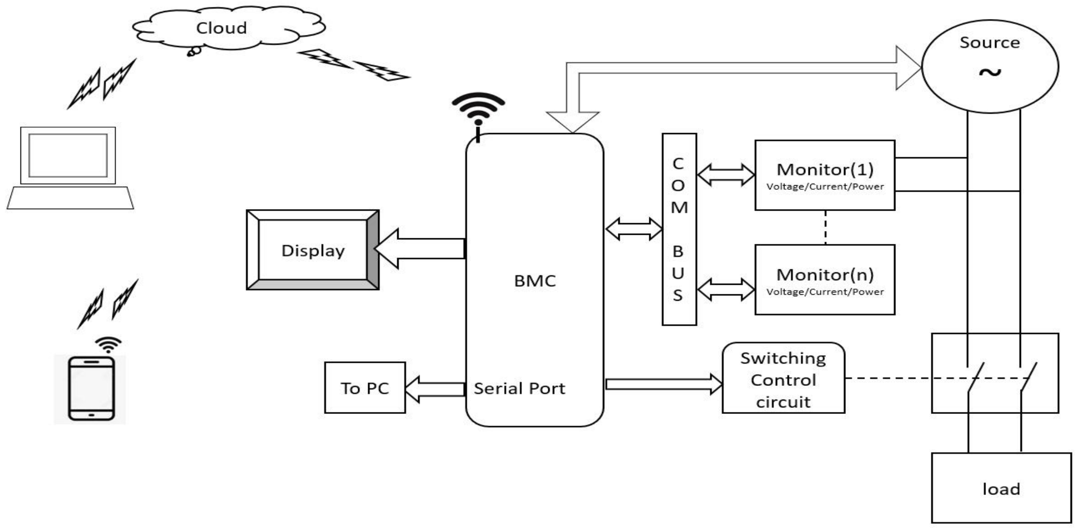

Figure 6: Block Diagram of Hardware implementation IPMI based Smart Grid

BMC is master part of smart grid system, which is connected with internet. It is managing the interface between sub-system (monitors, Switching circuit) software and platform hardware. The sub-system and the server exchange the data by means of BMC, in a secured and addressable mode. BMC collecting the data from sub-systems (Transmission, Consumer lines) and store the data then transmit to server.

4.1 Use case Analysis - Demand Awareness

Demand Response: Dynamic i.e. based on Load

Description: In an industrial area where there is a Vehicle Alloy Wheel Press Factory, along with other small consumers (factories).The Alloy Wheel Pressing Electrical Equipment will draw X KWH when the Alloy Press is fully in service and hence the overall power i.e. Voltage Current and Power flowing though the lines for that location is dependent on the factory working or Producing Alloy Wheels.

Assuming they have a full run of the production floor starting 6 AM to 3 PM. The energy device such as the distribution transformers catering to the factory and its surrounding shall work at maximum throughput in this time.

Power Demand: X KWH per Hour.

Step 1: The Energy Meter at the Alloy Wheel Factory shall sense the breaker for the HV equipment getting switched ON.

Step 2: The HV equipment ON timer is triggered on the Energy Meter in the Factory**.** This information is passed to the distribution substation's electronic control panels, by the Energy Meters. Medium of info transfer can be wired or over cloud.

Step 3: The electronic control panels shall communicate the demand to the generation plant via Cloud Service.

Step 4: The generation plant shall cater to the demand.

Step 5: Factory is able to run at its maximum efficiency.

Advantages:

1. Demand sensed and assertive demand response.
2. Manual intervention is not required when scenarios such as current state of affairs due to COVID-19 (or such scenarios). Demand response is dynamic based on the demand sensing.
3. When all devices in the network work with the same protocol and hence have understandable request response based interactions, any sophistication can be achieved.

5.CONCLUSION AND FUTURE FOCUS

Data interface, exchange and storage is key phenomenon in modern smart grid systems. A heuristic IPMI based communication protocol is researched in this paper. The data traffic, security, high number of sensors and actuators, concurrent information exchange are considered for the IPMI protocol design. IPMI enables smart grid to interact several software systems connected through cloud systems, thus ensuring the complete data transfer and maintenance. The architectural view points and the communication interface of IPMI smart grid proposal are discussed in detail.

Authors are progressing to implement the IPMI concept in smart grid architectural environment. Basic experimental setup depicting the generation, transmission, distribution systems along with cloud interface can be established with IPMI protocol enabled in a hardware setup. Such an experimental Hardware& Software implementation will pave the way to explore IPMI techniques in smart grid environment.

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APPENDIX A:

Distribution Substation, Regulator Settings Data Points: Reference [14]:

Metering Information:

Menu Item	Value	SGArch Device Descriptor	Comments
V load	220	#Dist.<nn>.Reg.<nn>.LoadVoltage	Load Voltage at Secondary of Transformer
V Source	7700	#Dist.<nn>.Reg.<nn>.SrcVoltage	Source Voltage at Primary of Transformer
I load	5	#Dist.<nn>.Reg.<nn>.LoadCurrent	Load Current at Secondary of Transformer
PF	1	#Dist.<nn>.Reg.<nn>.PowerFactor	Power Factor on Load Side.
Power	16 W	#Dist.<nn>.Reg.<nn>.Power	Power on Load Side.

Power Regulator Information:

Menu Item	Value	SGArch Device Descriptor	Comments
Tap Chngr:	RnR Co	#Dist.<nn>.Reg.<nn>.TapChngrOEM	Tap Changer OEM name
Type:	ST	#Dist.<nn>.Reg.<nn>.TapChngrType	Tap Changer OEM name
Syst:	WYE	#Dist.<nn>.Reg.<nn>.TransformerType	Transformer Type
DeltaPwr:	OPEN	#Dist.<nn>.Reg.<nn>.DeltaPower	Delta Power(Transformer)
Utility Pol:	NORM	#Dist.<nn>.Reg.<nn>.UtilPolarity	Utility Polarity
VprimaryMax:	65K	#Dist.<nn>.Reg.<nn>.PrimaryVoltsMax	Max Primary Voltage
U2 PT Primary:	7200	#Dist.<nn>.Reg.<nn>.U2PTPrimary	Potential Transformer PT-U2P
U2 PT Secondary:	120	#Dist.<nn>.Reg.<nn>.U2PTSecondary	Potential Transformer PT-U2S
P2 PT Primary:	7200	#Dist.<nn>.Reg.<nn>.P2PTPrimary	Potential Transformer PT-P2P
P2 PT Secondary:	120	#Dist.<nn>.Reg.<nn>.P2PTSecondary	Potential Transformer PT-P2S
CT Ratio Primary:	200	#Dist.<nn>.Reg.<nn>.CTRatioPrimary	Current Transformer Ratio Prim
CT Ratio Secondary:	0.2	#Dist.<nn>.Reg.<nn>.CTRatioSecondary	Current Transformer Ratio Sec
I Full Load:	200	#Dist.<nn>.Reg.<nn>.IFullLoad	Full load Current
Pwr Flow (mode):	F LOCK	#Dist.<nn>.Reg.<nn>.Flock	Power Flor Direction
Basis Volts:	120	#Dist.<nn>.Reg.<nn>.Flock	Basis Transformation Voltage
NeutOvRun:	2	#Dist.<nn>.Reg.<nn>.NeutralOverun	Neutral Overun
Memo1:	SS1	#Dist.<nn>.Reg.<nn>.Memo1	User Friendly Memo 1
Memo2:	SS2	#Dist.<nn>.Reg.<nn>.Memo2	User Friendly Memo 2
Version:	4.111	#Dist.<nn>.Reg.<nn>.SWVersion	SW or Firmware Version.