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Modeling of a Layered Architecture for Efficient Operation of Intelligent Power System

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***Abstract*— The present management and technical scenario of the Intelligent Power System presented in the paper substantiates the need, and forms the basis for development of a Layered Architecture of Intelligent Power System. The paper first explains the concepts and advantages of Layered Architecture. The evolving scenario of the integration of Computers and Information Technology with Power System is also studied. A *model of the Layered Architecture for Intelligent Power System* is presented in the paper. The elements, functions, services, data and control information of the various layers have been presented.**

***Index Terms*— Layered Architecture, Restructuring,Open-Source Architecture, Intelligent Power Systems**

I. Introduction

The three principal functional areas – Generation, Transmission and Distribution of an Electric Power System in the context of the present day scenario and technology are no more vertically integrated nor are purely electrical in technology. They have been un-bundled into separate organizations for effective management. The functional aspects have been computerized. This has paved a bifurcated path, demanding an approach of integrated study of the fields of Power Systems, and Communication and Information Technology. A Layered approach in the study of the vast expanding Power System Technology would definitely outweigh a unified approach.

The three major functional areas of the Power System in India, are now an unbundled model of Generation Companies(GENCO's), Transmission Companies(TISCO's) and Energy Service Companies(ESCO's).The technical functionality[1] of the three areas are also computerized in the present day and are data driven, geographically dispersed in the monitoring and control actions. The highly inter-disciplinary nature of the existing de-regulated power industry and the complexity associated thereby, has seeded a thought for evolving an architecture that would enhance the Planning and Maintenance Operations of the Power System and thereby the market structure.

The paper presents the need for a Layered Architecture, and thereby the various Layers of the Intelligent Power System Architecture have been identified. The functions, services, data and control information of the various layers have been presented.

II. NEED FOR LAYERED ARCHITECTURE

A Layered Architecture(LA) [2] approach for the development and maintenance of Power System is essential as the modern trend is Open-Source Architecture (OSA).OSA is defined as an architecture in which equipment of different manufacturers may be functionally integrated in a manner that makes the particular characteristics of individual devices transparent to the system. The LA supports the development of plug-and-play equipment and components. Plug-and-Play components are those that can be integrated with the existing system and used without the need to make any modifications.

Power Industry is restructuring the Operations. The present rate of restructuring is exponential in relation to a linear structure of the 20^{th} Century. The rate of integration of Electronics, Information and Communication Infrastructure can best be understood from the graph at figure 1.0.
Most present Power Systems and all of the Future Power Systems will be Intelligent Power Systems. An Intelligent Power System is composed of components which are equipped with computational and communication facilities in addition to performing the basic function for which they are designed. Future Power Systems will be a combination of traditional centralized generation with the DG and renewable generation. Layered Architecture of Power Systems supports flexibility and convenience in Engineering and Integration of Power System Technology with Power Industry Market scenario which undergoes a constant change.

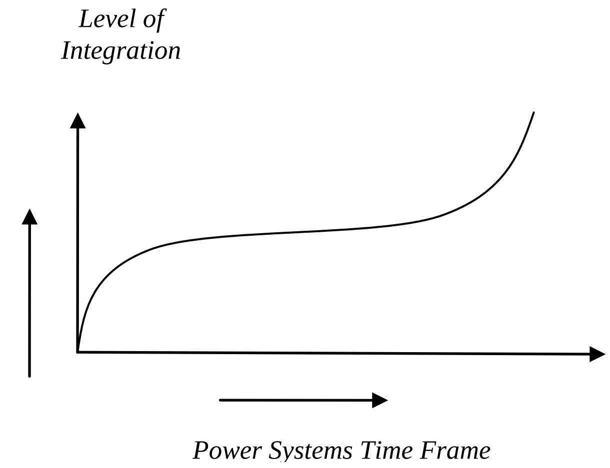
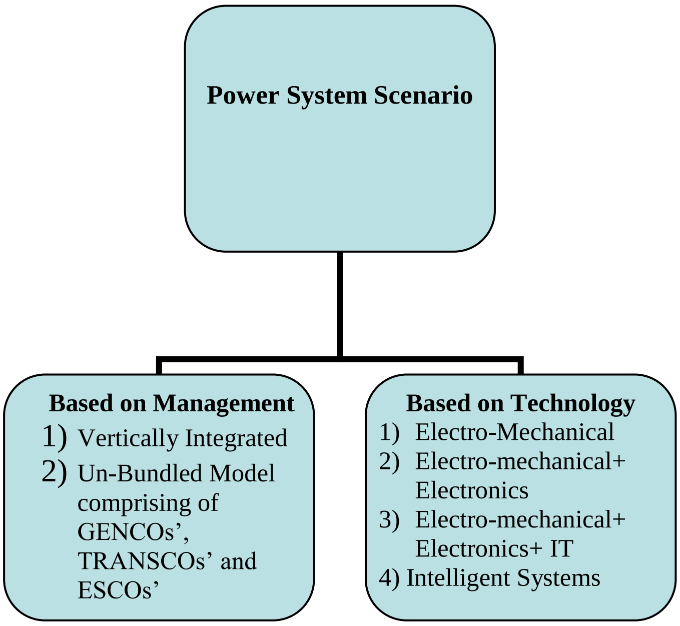


Fig.1.0 Level of Integration of Electronics, Computer and Information Technology (EC&IT) with Power Systems

III. RESTRUCTURING SCENARIO OF POWER INDUSTRY:

A. TAXONOMY:



The Concept of Layered Architecture has already been implemented and has been proved to be successful in the field of Communications [3] [4]. The 5-Layer TCP/IP and 7-Layer OSI are the two Layered Architecture Protocols governing the Computer Networks and the World Wide Web.

The need for Layered Architecture can be studied at two levels – Macro Level and Micro Level.

B.MACRO LEVEL:

At the macro level the need arises due to the Power Delivery industry encountering the following challenges:

- Liberalization and Globalization
- De-regulation
- De-Centralization
- Privatization
- More complex power – transmission and distribution standards
- Demand for real-time information
- New mandatory regulations from the government
- Growing demands for improvements in power quality, reliability and safety.
- Burdens of an ageing infrastructure workforce Additional Power Supply and sources that need to be integrated into the existing system.
- Increased requirements to improve security to protect the integrity of the system.
- Development of Distributed Generation.
- Development of IT and Power Electronics.
- Increasing Power Demand

The driving force for the future development of Power System is the further increase in the electrical power demand, based on expectations for increasing world population (1% per year), development of economy (2.4% average increase of economy (GDP) per year) and electrical energy being the most suitable form of energy with respect to commodity for people and environment (2.4% increase per year).

C.MICRO LEVEL:

At the micro level the need arises due to:

- Integration of automatic computing devices in modern Power Systems.
- Expanding functionality of the Power System components.
- Dynamic design and maintenance of Power System performance characteristics.
- Data driven operations.
- Need for Power System Communication Protocols to achieve interoperability.
- Power System Components entering into the Fifth Generation of Computing (i.e. Intelligent System).

- Need for Intelligent and cost-effective Distributed Automation of Power Systems.
- Increasing environmental constraints

(e.g. Co_2 reduction, regenerative power generation, will influence the type and location of new generation and changes in the structure of power systems.)

IV. WHAT LAYERED ARCHITECTURE IS ALL ABOUT?

Layered architecture is a modified version of the traditional '*Modular Architecture*'.

A. Modular Architecture divides the system into atomic components based on their functionality. The atomic elements are integrated in a systematic sequence to give the desired output. The atomic elements may be physical or logical in nature. Each atomic element can exist by itself to serve a specific purpose or be a part of a whole system to serve a purpose.

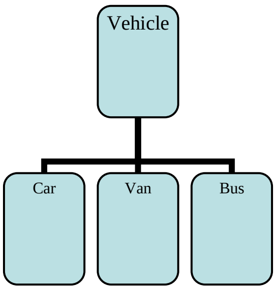


Fig. 2.0 Modular Architecture

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Access
Data Link Layer
Physical Layer

Fig.3.0 OSI .Layered Architecture

B. Layered Architecture: The modules are placed one-on-top of the other in the form of layers. We shall henceforth use the term Layer for modules.

"Layer is an architectural design pattern that structures the applications so that they can be decomposed into groups of sub-tasks such that each group of sub-task is at a particular level of abstraction".

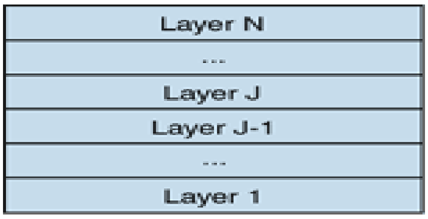


Fig. 4.0 shows how this layering Scheme would look

C. Advantages of Layered Architecture:

1. Better Planning.
2. Enhances Design.
3. Enables faster development of components.
4. Integration of different components developed by different manufacturers'
5. Enhances Fault Clearance time.
6. Reduction of maintenance time.
7. Smooth transition of Technology.

V. MODELING THE LAYERED ARCHITECTURE OF POWER SYSTEMS:

The Power System Components are organized in the form of Layers based on their functionality. The main principle behind Layered Architecture is that of "separation of responsibility". Each layer is responsible for a finite amount of work. Any work that cannot (read should not) be done by a particular layer gets delegated to a layer more appropriate for handling the task.

The two Major Layers of the Power System are

1. Power System Layer
2. Communication Layer

The table below shows the various Major and Sub-Layers of the Power System Architecture.

Table 1 Layers of Pow3er System Architecture

Major - Layer	Sub-Layer
1.Power System Layer	1.1 Hard-Core Layer 1.2 Sensing Layer 1.3 Monitor Layer 1.4 Control Layer
2. Communication Layer	2.1Communication Interface Layer 2.2 Information Transmission Layer

The Layers and the Interaction between the Layers of the Power System Architecture can best be understood by the diagram in Fig. 5.0 below:

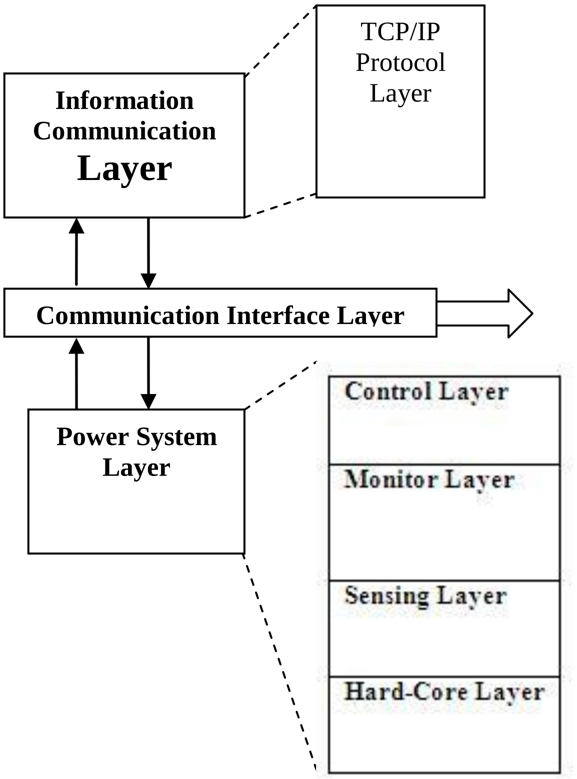


Fig. 5.0 Interaction between the layers of the Power system architecture

From the table we see that the two major layers in the *Power System Architecture* are:

1. Power System Layer constituted of
   1.1Hard-Core Sub-Layer
   1.2. Sensing Sub-Layer
   1.3. Monitor Layer Sub-Layer
   1.4. Control Sub-Layer
2. Communication Layer constituted of
   2.1. Communication Interface Sub-Layer
   2.2. Information Transmission Sub-Layer

VI .BRIEF FUNCTIONALITY OF THE POWER SYSTEM SUB-LAYERS

A. Hard Core Sub-Layer: It consists of the physical components of the Power System such as generators, motors, transmission and distribution lines, relays, Circuit breakers, transformers, switches, sensors etc that operate the power system or come into action when a fault occurs. The issues in this layer are designing the physical characteristics of the equipment for effective and efficient functioning. The design parameters should not only take into consideration the mechanical and electrical characteristics for effective electrical operations but also intelligently controlled operations. Size and capacity of the facility, location, connection among them, power flow, load flow characteristics power quality requirement are the features that encompass this layer.

It also encompasses the design and selection of pilot relaying scheme. Pilot relaying schemes are used for the protection of transmission line sections. They fall into the categories of unit protection. In this scheme some electrical quantity at the two ends of a transmission line are compared. Hence, information is to be transmitted from one end to the other. Such an interconnection channel is called a 'pilot' A pilot may be a telephone cable, power line or a micro wave carrier.

The advantage of Layered Architecture is that it will enable development of micro – controllers and power system components independently. The independently developed micro –controllers and power system components can be integrated for effective functioning.

Models can be created and various aspects of the system can be studied. Several software's' are available to model the physical layout of the various components of the power system and conduct simulation and analysis study.

B. Sensing Layer: This layer consists of the logical aspects of the sensors and transducers [5] that measure the physical quantities to be monitored and controlled such as voltage, current, frequency, reactive power, temperature. The Physical quantities are measured directly or a parameter proportional to the quantity is captured. These parameters indicate the quality of transmission and enable determine the parameters to be monitored to improve power system stability and efficiency. Real –Time data is captured and transmitted to the Monitoring Layer.

The parameter measured may be in analog or digital signal form. The signal is to be converted to digital data form for processing.

In ac transmission one important aspect that requires extensive study for improvement in performance is 'Loop Flow'.

Loop Flow: Power Flow in a grid is determined by the electrical characteristics of the lines involved. Power flowing from one point to another does not necessarily takes the shortest path, but flows through unwanted paths, generating additional losses, delay of transmission and distribution, and interference with neighboring sections in a pool operation.

This problem can be handled by dynamically determining the optimum path to transmit power at the shortest time.

The basic sensors may be Current Transformers, Voltage Transformer relays, level gauge, pressure gauge, flow meter, biometric temperature element etc.

The design issue in the sensing Layer is:

1) Identifying the factors to be monitored and controlled called as *'controlled parameter'.*
2) Identify the factors that affect the controlled parameter. These factors are the variable – dependent and independent variables.
3) Select the sensor suitable for the variables.

C. Monitoring Layer: The Monitoring Layer consists of multiplexers and RTU (Remote Terminal Unit). The value of the parameter measured at the Sensing Layer is transmitted to the Monitoring Layer. The measured value is compared with the designed level and the deviation is forwarded to the Control Layer for corrective action.

The Monitoring Layer encompasses the function of Data Acquisition at remote terminals. When multiple sensors are placed in the physical environment, their placement and the models of the events they are supposed to capture play an important role in the information extraction and assimilation. The spatially and temporally correlated information obtained from distributed sensors is processed to determine several aspects of the sensors for effective monitoring, control and operation of the power system.

D. Control Layer:_The Control Layer initiates the control action. The Layer can also be defined as the ‘Action Layer’. Control signals are sent through Communication channels such as fiber cable, coax to activate the control equipment such as circuit breakers isolators and sectionalizers. A concrete event occurs for a specified action.

It receives the deviation values from the Monitor Layer and initiates the control action.

VII. CONCLUSIONS AND FURTHER RESEARCH:

Modeling the Organization of the various components of the Intelligent Power System and the functions and issues of the Layers is an efficient and effective methodology of developing and maintaining Power System. There is scope for detail study of the various layers, their functions and services. The various protocols that govern the Integrated Power System Operations such as Modbus, DNP3.0 are to be identified and their integration modeled to improve the efficiency of Power System Operation by operations such as dynamic network configuration.

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