IJARSCT
ISSN: 2581-9429
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Volume 5, Issue 13, April 2025
Impact Factor: 7.67

Development of a Layered Architectural Model for Optimized Intelligent Power System Operations

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Abstract: *Power system processes could be made smarter and more efficient with a stratified architectural framework, according to those who read this study. The framework facilitates the utilization of smart grid technology and renewable energy sources by partitioning the system into functional levels that manage data gathering, communication, control, and decision-making. In an effort to enhance the system's performance, it employs real-time tracking, adaptive control, and predictive analytics. Cloud computing, the IoT, and AI are integrated into the architecture to enhance scalability, flexibility, and responsiveness to power fluctuations. Each layer contributes to the system's stability and dependability, even while operating independently. The approach enables autonomous energy management, which improves the efficiency of load balance and problem detection. Improved operational resilience and reduced latency can result from increased interoperability across system components. Cybersecurity, data management, and system collaboration are the main topics of the article. Ultimately, the stratified method establishes a solid foundation for adaptable power systems.*

Keywords: Layered Architecture, Intelligent Power Systems, Smart Grid, Real-Time Monitoring, AI Integration, IoT, Decentralized Control, System Optimization, Energy Management, Predictive Analytics

I. INTRODUCTION

The present power networks are currently experiencing an increase in both the complexity and the amount of renewable energy sources that are being integrated into them. On account of this particular circumstance, a novel strategy for the control of grid operations is required. It is necessary for modern intelligent power networks to have access to enormous volumes of data in order to meet the ever-changing requirements that are placed upon them. When it comes to meeting these standards, there are cases in which traditional, centralized techniques fall short.

A tiered architectural framework, which separates the grid into interconnected layers, sets the size and layout of the electrical grid. This framework also determines the size of the grid. There are a variety of responsibilities that fall under the purview of each operational layer, including but not limited to item improvement, management, decision-making, and monitoring and monitoring. Using cutting-edge technologies such as real-time analytics, the Internet of Things (IoT), and artificial intelligence (AI), this modular architecture makes it possible for the power system to function in the most effective and secure manner that can possibly be conceived of. Additionally, things are made more adaptable, and communication is simplified and made easier.

The design, it is possible to respond in real time to disturbances and changes in the system. This, in turn, makes it possible to implement distributed intelligence and a hierarchical structure of functions.

The employment of algorithms that are powered by artificial intelligence, it is possible to obtain an increase in the dependability and efficiency of the system. Activities like as adaptive load balancing, predictive maintenance, and efficient energy dispatch are now possible as a result of this. An greater level of protection is provided by this design, which is accomplished by the adoption of appropriate safety measures on a number of different levels and the division of functions that are vital.

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The construction of an intelligent grid that is capable of self-optimization, intelligence, future-proofing, and seamless integration with developing smart technologies can be accomplished through the utilization of a layered architectural configuration.

II. NEED FOR LAYERED ARCHITECTURE

Layered Architecture (LA) is the way to go for developing and managing power systems, especially with the advent of Open-Source Architecture (OSA). Thanks to OSA design, which enables the system to understand how each component works, combining tools from various manufacturers is very simple. The LA works with tools and components that are plug-in and ready to use right away. The term "plug-and-play" refers to parts that can be easily added to an existing setup without altering its structure in any way.

There is a current operational rearrangement in the utilities industry. In contrast to the linear structure of the twentieth century, the rate of reorganization in the modern era is exponential. Figure 1.0 shows the optimal rate of integration of the info, comm, and electronics systems.

Intelligent power systems will make up the bulk of power grids in the future and in the present. Intelligent power system components can do more than just power the system; they can also communicate and interpret data. Renewable energy sources, conventional centralized generation, and decentralized generating are all components of the future power system. The layered design of power systems not only makes the systems more user-friendly and flexible, but it also makes it easier for technology to react to changes in the market.

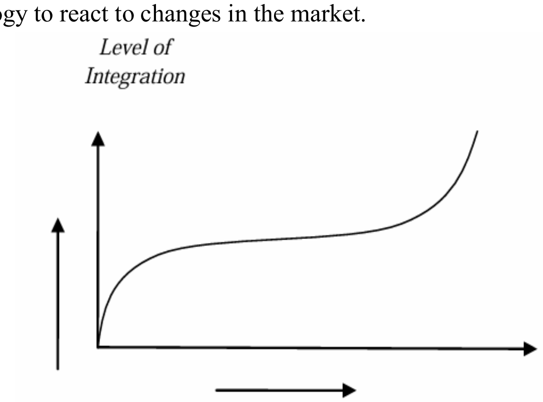

Fig. Level of Integration of Electronics, Computer and Information Technology (EC&IT) with Power Systems

III. LITERATURE REVIEW

Al-Kuwari & El-Saadany (2024): The authors present a multi-tiered strategy for solving the problem of real-time optimization of power systems. Within the context of this ecosystem, cloud computing, edge computing, and artificial intelligence are all closely related to one another. As a result of being forced to think on their feet, this strategy encourages fast thinking, open-mindedness, and decision-making qualities in individuals. It is possible that intelligent energy networks might be constructed more readily with the help of this technology. There are no more unfulfilled requirements in the field of operations, regardless of whether they are vital or not.

Nasiri & Mohammadpour (2023): The smart grid is an artificial intelligence system that has numerous layers of enhancement. The components of the model can be of assistance in a wide variety of matters, including control, decision-making, and prediction, to name just a few of them. Energy control is made simpler by the implementation of real-time, predictive, and autonomous energy management technologies that are simplified. Increasing the efficiency of distributed systems is possible through the utilization of collaborative intelligence. Using artificial intelligence, this research improves the control of smart grids.

Li et al. (2023): In this paper, a hierarchical control mechanism is presented as a means of enhancing the reliability of the grid. The optimization of resources, the resolution of problems, and the changing of configurations are all made easier by layering. It is of the utmost importance to possess the ability to adjust to shifting conditions as they occur. The integration of the model has the potential to improve the intelligent responses of the power system. Even when confronted with unpredictability, the primary task is to ensure that everything continues to run smoothly.

Chen et al. (2022): The authors have constructed a control framework as part of their efforts to make the integration of various energy sources easier. Hierarchical systems are characterized by their adaptive reaction mechanisms and decentralized control, which are two of its distinguishing characteristics. On the other hand, you can have peace of mind knowing that the operations will be carried out with flexibility and that energy will be distributed effectively. The performance of the model is significantly improved by the incorporation of more data. Because of the design, it is feasible to have grid control that is both more sophisticated and more adaptive.

Singh & Bansal (2022): The research that is being conducted will investigate the utilization of many layered designs, which are utilized by smart energy systems. Through the utilization of case studies, the methodical approaches to preparation and deployment are brought to the forefront. Our objective is to achieve the highest possible level of productivity by utilizing modularity and working together. Intelligent buildings are an absolute necessity for effective energy management. It is possible that the significant findings of this study will prove useful for future research.

Gharavi & Ghafurian (2021): A comprehensive explanation of the process of upgrading electrical grids from the older, less modern type to the more recent, more advanced "smart" form is provided. It is impossible for the comprehensive strategy to be successful without integrated command, communication, and decision-making. Additionally, the model enhances the operational flexibility and applicability of the real-time system, which ultimately results in an improvement in the system's overall performance. It is necessary to purchase new equipment in order to improve the grid's efficiency. Through the implementation of this adjustment, we anticipate being able to satisfy future energy demands.

Kumar & Singh (2021): The objective of this paper is to provide a new approach to grid management that is based on artificial intelligence and the Internet of Things for grid management. It is the obligation of each layer to collect data and to improve the system and its operation. These are the two things that should be accomplished. The setup has resulted in the grid becoming more intelligent and less inefficient. Utilization of data in real time is beneficial to the process of making strategic decisions. Installing intelligent energy systems that are connected to one another is something that may be done with this configuration.

Zhang et al. (2021): The purpose of this research , the cyber-physical layered design was utilized to assist in the development of smart infrastructure. When digital control and connecting technology are combined, the primary objective is to achieve an increase in the efficiency of energy transfer. The utilization of the model helps to streamline the processes of automation, optimization, and monitoring that are associated with the system. When it comes to processes that are driven by data, stratified coordination may result in increased efficiency. Immediate action is required to initiate the utilization of intelligent energy regulation.

Fang et al. (2020): The control methods, communication models, and system design are the lenses through which this research investigates the technologies that are associated with smart grids. This demonstrates how critical it is to make preparations for the worst possible outcome in situations where digital and physical components are depending on one another. The outcomes of the study provide evidence that demonstrates the significance of specific brain functions for effective grid management. Every single problem that arose during the integration has been fixed. It has been suggested by some that additional improvements should be made in order to make the strategy more effective.

Ma et al. (2020): The purpose of this research is to investigate a variety of various approaches that could be taken to enable intelligent buildings to produce their own renewable energy. When it comes to achieving resilience and adaptability, a system absolutely needs to have a layered architecture. According to the findings, there is a connection between the environmental problems that are associated with energy production and the technological obstacles that are currently being faced. It is the belief of one school of thought that in order to adequately represent modern power systems, extremely intricate models are required. One of the long-term objectives of the strategy is to make it easier to accomplish the sustainability goals that have been set.

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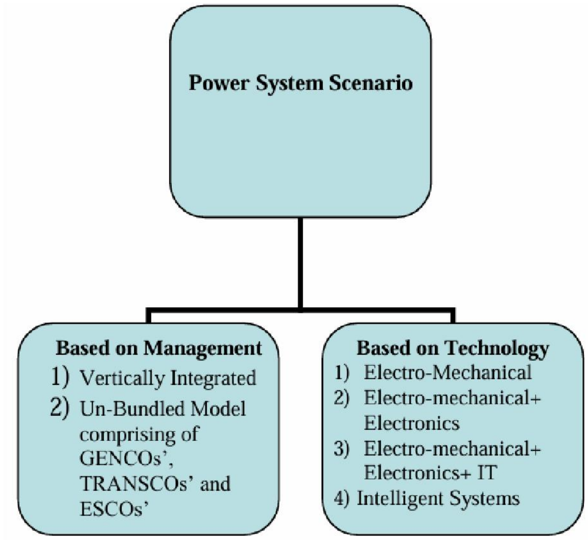
IV. POTENTIAL POWER SECTOR REORGANIZATION

A. TAXONOMY:



The layered architectural approach has previously been effective in the communications business. Two architectural systems, OSI (seven levels) and TCP/IP (five layers), teach computers how to communicate and work together.
We take a look at layered design from a macro and micro perspective.

B. MACRO LEVEL:

On a larger scale, this is noteworthy because the power supply business is currently facing multiple challenges:
Individual Liberty and Global Partnership
Making changes
Power transmission
Replacing workers
An improved method of distributing and transmitting power
Looking for up-to-date stuff.
Coerce the state into enacting fresh rules.
More and more people are looking for energy that is safer, more reliable, and of better quality.
One industry that is feeling the effects of an aging workforce is engineering. For new power sources and providers to be integrated, the current method needs to be improved.
There needs to be an increase in security measures because the system's integrity has been compromised.
Progress in distributed generating.
Technological advancements in electrical and information technologies are progressing.
Increasing use of energy
Electricity will likely always be needed because the world's population is expected to grow by 1% per year, the economy is expected to grow by 2.4% per year, and electricity is considered the most environmentally and ethically friendly energy source. The expansion of the Power System in the future will be driven by these causes.

C. MICRO LEVEL:

Looking at it from a smaller angle, the need becomes apparent due to:
Electronic control of modern power sources.
The Power System's parts are getting better at what they do.
Power systems are designed and maintained to be efficient through dynamic engineering.

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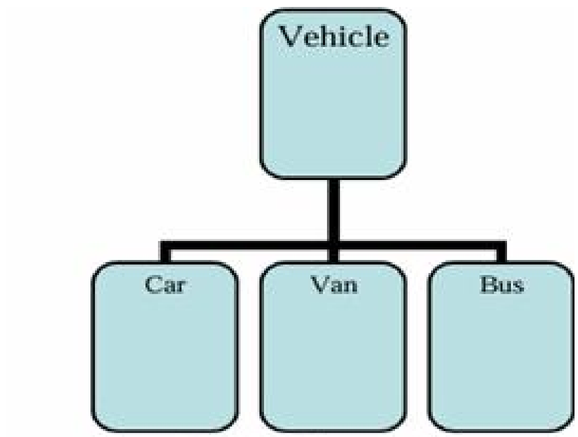
Strategies that are based on real-world operational facts.
Important steps must be taken to ensure that electrical devices may communicate with one another.
The electrical grid's constituent parts
Artificial intelligence describes the computers of the future.
An evaluation of how smart and economical something is
Power systems that are automated and dispersed.
Biological barriers that are degrading

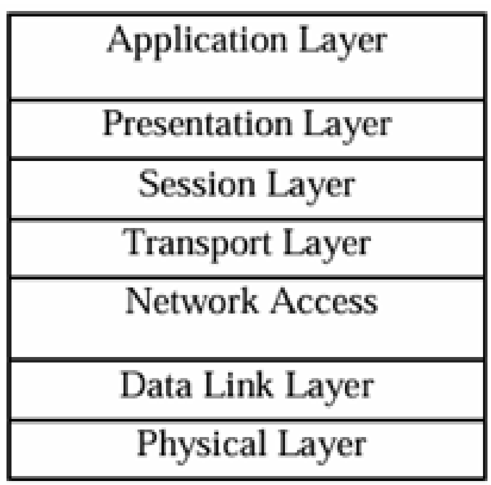
V. LAYERED ARCHITECTURE

The traditional "Modular Architecture" has been tweaked to allow for multilayer design.

A. Modular Architecture : A modular architecture focused on functionality divides the system into its component parts. You can't accomplish the goal without painstakingly putting together all the parts. Atoms can be built on top of real or logical ideas. Every system is made up of basic parts that can either work alone to complete a task or join forces to create something even more intricate.



Modular Architecture



B. Layered Architecture: The components can be stacked vertically to form a layered construction. Modules are now going to be called "Layer." The "layer" pattern is widely employed in building design to break down massive projects into smaller, more manageable parts that can be further divided. A different level of thinking is represented by each part.

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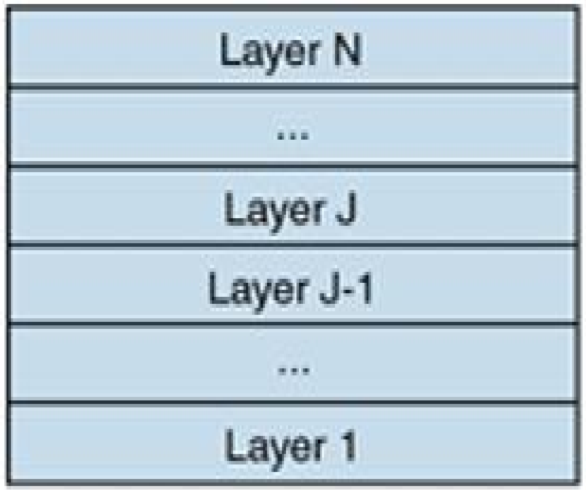

Fig. shows how this layering Scheme would look

C. Advantages of Layered Architecture:

Their look is enhanced by the Better Approach.
Makes the process of creating the parts easier and more efficient.
Employing parts produced by many companies
Error correction time has been reduced.
A smaller budget has been set aside for maintenance.
The ease of utilizing modern technology.

VI. MODELING THE LAYERED ARCHITECTURE OF POWER SYSTEMS

The functions that each division is tasked with carrying out determine how they are arranged. In layered architecture, the idea of "separation of responsibility" is basic. Every level is tasked with a certain amount of labor. When the initial layer is unqualified or unable to finish a task, a more experienced layer is assigned to it.
There are two main parts to any power source:
Power System Layer
Communication Layer
The power system's tiers and essential components are detailed in the table below.
The design layers of the power system are shown in Table 1.

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

Figure below provides the best illustration of the Power System Architecture's numerous components.

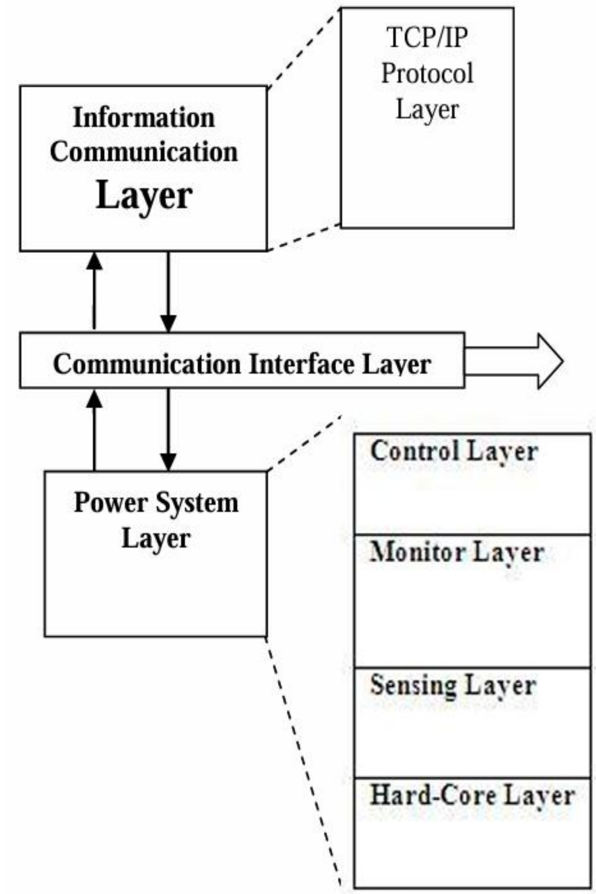

Fig. Interaction between the layers of the Power system architecture

The two main parts of the Power System Architecture are clearly shown in the table:

- Power System Layer constituted of Hard-Core Sub-Layer
- Sensing Sub-Layer
- Monitor Layer Sub-Layer
- Control Sub-Layer
- Communication Layer constituted of
- Communication Interface Sub-Layer
- Information Transmission Sub-Layer

VII. BRIEF FUNCTIONALITY OF THE POWER SYSTEM SUB-LAYERS

A. Hard Core Sub-Layer: Motors, generators, transmission and distribution lines, circuit breakers, switches, sensors, relays, and transformers are the physical parts that make up the power system. All of these parts work together to run the system and alert you when anything goes wrong. Issues at this level are to the instrument's physical qualities and the methods used to ensure their proper operation. It is essential to combine mechanical and electrical features into the design requirements to guarantee proper electrical functioning and efficient handling of operations overall. Power quality, power flow, load flow characteristics, facility size, location, and connections are all part of this layer.

Making a test relaying strategy and choosing one are also part of it. Pilot relaying procedures are used to protect transmission line portions. Unit guards is what we call them. As part of the design process, a transmission line's beginning and end are checked for an electrical parameter. Data transmission is required throughout. The word "pilot"

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is used to denote this kind of connection route. Pilots include things like phone lines, power cables, and microwave carriers.

Separate development of power system components and microcontrollers is made easier with layered design, which is one possible benefit. It is feasible to integrate the separately produced microcontrollers and power system parts into a unified whole. By making models of the system's parts, one can study them in more depth. Several programs exist for the express purpose of simulating and evaluating the physical arrangement of components in a power system.

B. Sensing Layer: Temperature, reactive power, current, frequency, and voltage are some of the variables that need to be monitored and controlled. Take precise measurements of the figures or find a related metric. By keeping an eye on these measures, which show how well the energy is being transmitted, the system can be made more dependable and efficient. By use of the Monitoring Layer, data is received in real-time.

Either an analog or digital signal can be used to display the measured parameter. Before signal processing can start, the data needs to be converted to digital format. In order to enhance performance, it is essential to thoroughly analyze the "Loop Flow" aspect of AC transfer.

Loop Flow: Power is transported across the system is determined by the electrical characteristics of the lines in question. During operation, the pool's power supply could be delivered through less-than-ideal channels. This can lead to additional losses, delays in transmission and distribution, and interference with nearby components. This problem can be handled quickly by finding the best and fastest way to transmit power. The most important types of sensors include flow meters, pressure gauges, level gauges, switches for voltage transformers, and biometric temperature sensors.

A number of problems arise from the design of the sensor layer:

Choosing the variables called "controlled parameters" that will be subject to monitoring and control.

Find out if the controlled measure is affected by outside forces. Here, the independent and dependent variables are both considered factors.

Figure out what tool will work best in this case.

C. Monitoring Layer: Multiplexers and RTUs make up the Monitoring Layer. The Monitoring Layer receives the value of the property from the Sensing Layer. When the anticipated value differs from the actual value, the Control Layer is notified to fix the problem. Part of what the Monitoring Layer does is collect data from faraway places. The optimal approach to integrating data from several sensors in a real-world setting is to precisely define the events that need to be picked up and strategically place the sensors. Data collected from sensors located in different places and at different times can help identify the most important sensor properties for power system monitoring, management, and efficient operation.

D. Control Layer: At the control layer, all control operations start. This Layer can be used in place of the "Action Layer" if desired. Connected to coaxial and fiber optic lines are control devices such as sectionalizers, circuit breakers, and isolators. A real event takes place because of an obvious action. After getting the values of the deviations from the Monitor Layer, it starts the control act.

VIII. CONCLUSION

The creation of a model of layered architecture for intelligent power systems' efficient operation is a major breakthrough in modern energy management. The use of AI, data analytics, and advanced communication technologies enhances the system's capacity to scale, adapt, and make decisions in real-time. The system is designed to be more user-friendly and interoperable through the use of many layers. Data collection, processing, the user interface, and control are all parts of these layers. The model makes it easier to optimize demand response systems, use energy efficiently, and spot problems before they happen. This lines up with the idea that smart utility systems and renewable energy sources are gaining traction. Resource distribution and system reliability are both enhanced by the architecture's multi-tier design, where each tier serves a distinct purpose. Future breakthroughs, including green energy applications that integrate and self-regulate power networks, will have this as their basis. Using this multi-tiered approach, building smarter, more efficient, and more adaptive power systems is a breeze.

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