Panchamrit Tree: A Smart Sustainable Utility Eco Friendly Management Based System

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Abstract: The concept of Panchamrit Tree is a holy concept based on the combination of different engineering platforms which comes together to bring a healthy change based on sustainable and innovative concept mostly needed for improving the urban infrastructure.

This tree is a smart technology-oriented tree which is designed to face and overcome multiple challenges under one roof by integrating different platforms into a single platform. It is designed to sustain and address multiple environmental condition, generate green energy, improve communication and helpful for public utility services.

The structure of this tree is wholly inspired through natural tree. The function of this tree is almost same as that of natural tree as its entire system combines technologies based on advance concept that is Artificial Intelligence (AI), Internet of Things (IoT), Renewable Energy based Stand-Alone Power Supply (SAPS) System, Antennas for Communication System, Public Utility Management System. This all together provides an eco-friendly and smart city management solutions. It is a self-sustainable system.

The model of this tree is incorporating Renewable Energy System (RES) in different manners such as its leaves designed in the form of solar panel, Branches are designed to produce wind energy, Bottom Stem have biomass chambers, Middle Stem have air purifiers system. Top Stem have traffic signal control units, surveillance systems. Devices equipped with AI and IOT systems along with different sensors helps to monitor real time data continuously. It keeps close eyes on environmental parameters such as air quality, temperature, humidity, noise levels, traffic density and energy consumption, enabling intelligent decision-making.

The nodes of this tree are designed to serves for communication-based system which can be used for public utility management system. It has Wi-Fi, Digital display information system, Traffic Management System.

This tree also has Electric Vehicle (EV) charging system and Street lighting System. This innovative solution contributes significantly to achieving sustainable development goals, improving urban living standards, and creating resilient, energy-efficient and environmentally responsible cities of the future.

Keywords: Artificial Intelligence, Internet of Things (IoT), Renewable Energy, Air Purification, Street Lighting, Traffic Management, EV Charging Station, Sustainable Urban Development, Real-Time Monitoring, Green Infrastructure.

Introduction: The idea of Panchamrit tree is taken from Hindu mythology where fourteen precious gems came out after sea churning. The two trees that is ***"Kalpavriksha and Parijata".*** The rapid increase in modernisation and urbanisation in the cities worldwide with limitation of land the entire world is facing a major challenge in the form of traffic congestion, overloads on public utility services, heavy pollution in the environment, lots of jams, heavy demands in energy. To overcome this situation the concept of smart cities has emerged now a days. It is now becoming one of the promising major remedies to tackle or address these challenges. The technologies-based solution has shown us a path to minimise these challenges up to an extent.

The Panchamrit tree is inspired from the slok taken from ***"Shree Mad Bhagavad Gita" Jee*** mentioned in ***(Chapter 10, Verse 21).***

"Sanskrit (Original Verse)"

आदित्यानामहं विष्णुर्ज्योतिषां रविरंशुमान्।

मरीचिर्मरुतामस्मि नक्षत्राणामहं शशी॥

"Hindi (Translation Verse)"

मैं अदिति के बारह पुत्रों में विष्णु और ज्योतियों में किरणों वाला सूर्य हूँ तथा

मैं उनचास वायुदेवताओं का तेज और नक्षत्रों का अधिपति चन्द्रमा हूँ॥

"English (Translation Verse)"

Of the Adityas (the twelve sons of Aditi), I am Vishnu; of luminous bodies,

I am the radiant Sun; of the Maruts (the storm deities), I am Marichi; and among the stars, I am the Moon.

This inspire and knock to think and combine the technologies under one umbrella and design a Panchamrit tree. This tree is a smart tree which is equipped with various technologies that

aims to craft a self – sufficient, sustainable, durable and intelligent ecosystem especially designed for urban area.

Fig 1: The Panchamrit Tree

This tree has RES system for generating Green Energy, Communication system, Air purifiers system, Surveillance cameras, Street lighting, Public Addressing System, Digital Display System, EV Charging, Traffic management system (Traffic Signals) controllers, IoT for sharing real time data, A I to share, analyse and monitor the entire system. The requirements for predict maintenance can be easily managed A.I techniques.

Overall, this tree represents a complete combination of different technologies that leads towards the integrated methods to various technologies that is much demanded to manage the smart sustainable system to overcome urban problem of congestion. This holistic proposed system not only approaches to improve the quality of urban life but helps to uses and manage cleaner, greener and more resilient cities for future generations.

Working Concept: The concept of Smart Panchamrit Tree is similar to normal tree where different parts are essential for proper functioning likewise in Panchamrit Tree there are different modules which are integrated together to form this tree. Basically, the Panchamrit Tree is a multidimensional utility ecofriendly artificial tree which has RES, Communication network system, environmental protection, intelligent traffic management, real time data driven system, IoT Sensors, Air purification system, public utility and addressing system, A.I, EV Charging as per the Smart City Technologies for sustainable urban and rural development.

Module 1: Hybrid Renewable Energy Source (HRES) for Generating Power

The Smart Panchamrit Tree works on SAPS system that helps to generate clean and green electricity on through multiple renewable sources.

a) Solar Power Generation: The leaves of tree are designed in the form of solar photovoltaic plates for converting sunbeams into electrical energy and battery bank is coupled with it for storage purpose and continuous operation.

b) Wind Power Generation: Small, Compaq and light weight wind turbines having vertical axis and horizonal axis type of orientation which fans can be closed like an umbrella are mounted along the limb, twigs and branches of a tree so that generation of power can be continued in cloudy, rainy and at night time. As energy of wind can be converted for generating electricity.

c) Biomass Energy System: The lower part of trunk can be used as biomass collection where natural waste or organic waste can be put in (leaves, grasses, biodegradable waste and residues of agricultural products). They biomass is processed through a biogas or gasification unit to generate electricity. The residue obtained from biomass plant can be used as a fertilizer.

Hence the three different methods of generating electricity in module 1 can supplement each other and we can manage to store the generated energy in battery banks for further use and we can obtain clean and green power.

Module 2: Communication System

a) Antennas: The top of the Panchamrit Tree a structure is designed where antennas are installed according to the cluster so that peoples can get proper signals for communication. This will enhance transmission of data and also support services like Wi-Fi, 5G/6G small cell networks, hotspot, increase internet connectivity, emergency communication services in public places.

b) Intelligent Traffic Signal Control: The tree is equipped with surveillance camaras, smart traffic control systems sensors that works on real-time traffic flow which helps in the reduction of congestion with minimum waste of time. It helps to reduce accident and improve the ability of road safety.

Here the two systems used for communication system provides an upper hand to communicate, improve traffic management system in a smart manner.

Module 3: A.I and IoT system

a) A.I System: The AI enable system helps to continuous and monitor the entire system. It guides for the predictive maintenance steps, helps in handle smart energy management system. The power generation and consumption can be closely monitored by using AI-based energy controller. When pollution levels increase the AI based controlled air monitoring sensors activate purification systems. The brightness level of light can be automatically adjusted by using AI sensor which helps in energy saving. AI based sensor helps to monitored the battery health and increases the life spam of it.

b) IoT System: It helps to monitor the hole unit on real time basis. It transmits the data to central cloud platform and enhance the monitoring and analysis system. The various sensors based on IoT provides upper hand in monitoring and handling batter management system (BMS), air quality index (AQI), traffic congestion and other useful parameters.

Module 4: Public Utility Services

Public utility services are one of the major components of this tree. It helps to address, guide and support the services related to public. The system helps us to avail services such as EV charging, know AQI, traffic congestion, mobile charging station, Wi-Fi and internet, weather information services and emergency call systems. It also enhances road safety by increase in awareness and support emergency call systems

Module 5: Smart Energy Management

The concept based on handling smart method of energy management system helps us in street lighting, decorative system, digital display of signals, AQI, public utilities, surveillances system, boost communication systems, maintenance system along with battery management system.

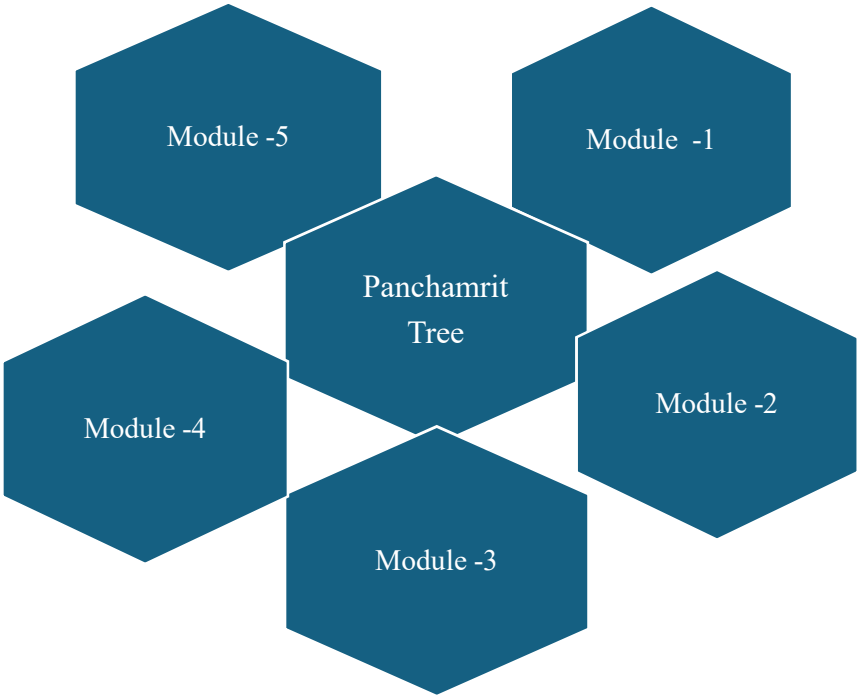

Fig 2: The Panch Structure Module

Financial Prospective: To do the cost analysis of this tree which is based on multi-effective function we have to integrate all the five different modules in a single frame that is the Panchmrit tree. Certain assumption is considered as a phototype on preliminary cost in term of Indian Rupees (INR). The estimated cost of the following basis:

Sr.No.	Components	Cost in Lacs in INR
1.	Steel Structure for Tower frame work	425000
2.	Solar PV Panel (4 KW)	275000
3.	Wind Turbine (8×0.5 KW = 4KW)	240000
4.	Biomass set up prototype	250000
5.	Battery Bank	300000
6.	Inverters	150000
7.	IoT and A.I based Sensor and Controller	215000
8.	Air Purifier System	135000
9.	Smart Traffic Control unit	125000
10.	Steet Lighting, Public Addressing System	145000
11.	Digital Display System	75000
12.	Communication equipment (Antennas, Wi-Fi, Networking)	275000
13.	EV charging Station Setup (AC,6-12KW)	265000
14	Cable and wiring Cost	125000
15	Earthing Cost	35000
16.	Panel Cost	185000
17.	Civil work Cost	175000
18.	Transportation and Handling Cost	300000
19.	Software integration and testing cost	165000
	Total	**3958000**

Table 1: Cost of Components in Lacs

Contingency (Approx 10%) of overall cost that may very 36-44 lacs, therefore the cost of one Panchamrit tree vary on the above basis from place to place.

Other factors that have to be consider on cost wise in INR

1. Annual maintenance cost of tree - 125000
2. Battery maintenance cost - 15000
3. Preventive maintenance cost - 105000
4. Software updating cost - 15000
5. Cloud and Data maintenance cost - 10000

Total Annual operation and maintenance cost - 270000

Now cost based on various assumption they may be considered as initial cost and annual maintenance cost (AMC)

i. Initial cost of setup - 4000000
ii. AMC - 270000

Net payback period - 5 years and Net annual profit 8 Lac. Now in terms of rate of investment (ROI) on 10year basis

From 1 to 5year recovery of investment (initial) - 0%, On 5th year Break Even Point (BEP) will be achieved now from 6 -10year 100% return on ROI at the rate 8 eight Lacs per annum.

The AMC for the three years is nil as it comes under warranty period and after that it is applicable.

Sr.No	Year	ROI	%
1	0	-40	-100
2	1	-32	-80
3	2	-24	-60
4	3	-16	-40
5	4	-8	-20
6	5	0	0
7	6	8	20
8	7	16	40
9	8	24	60
10	9	32	80
11	10	40	100

Table 2: Year wise percentage of return

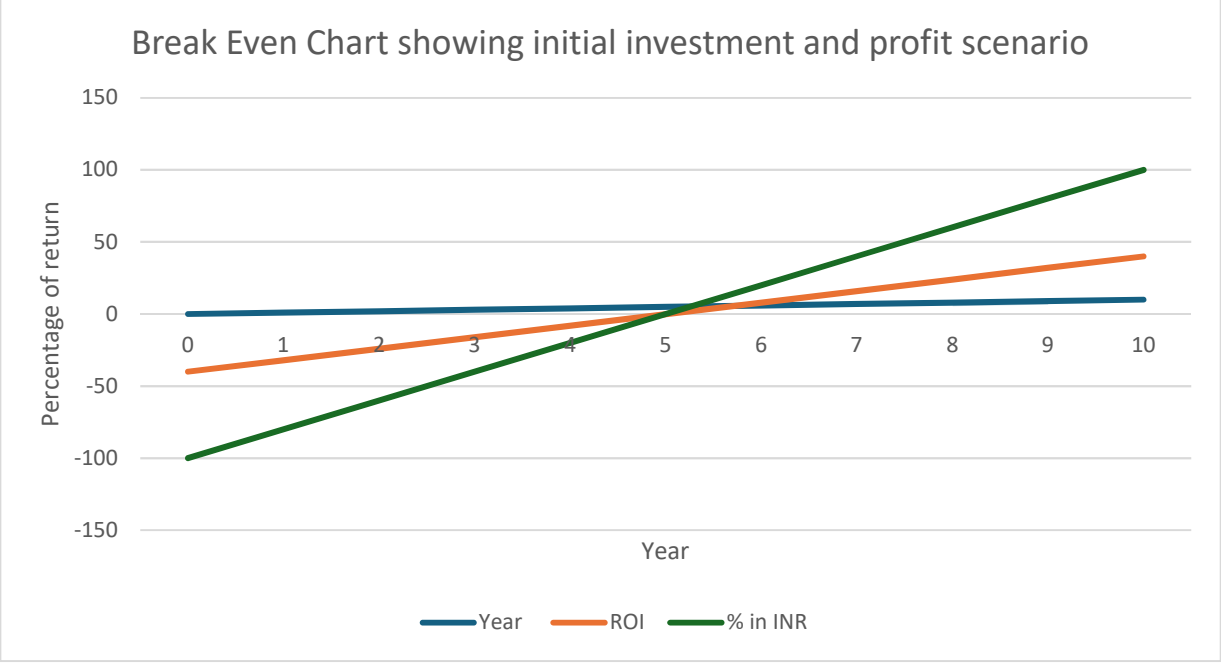

Fig 3: Break Even Chart

Architecture of Integration: The method of integrating all different five modules together so that the combine together in a single structure and maximum utility can be derive from this tree. The workflow according to the diagram

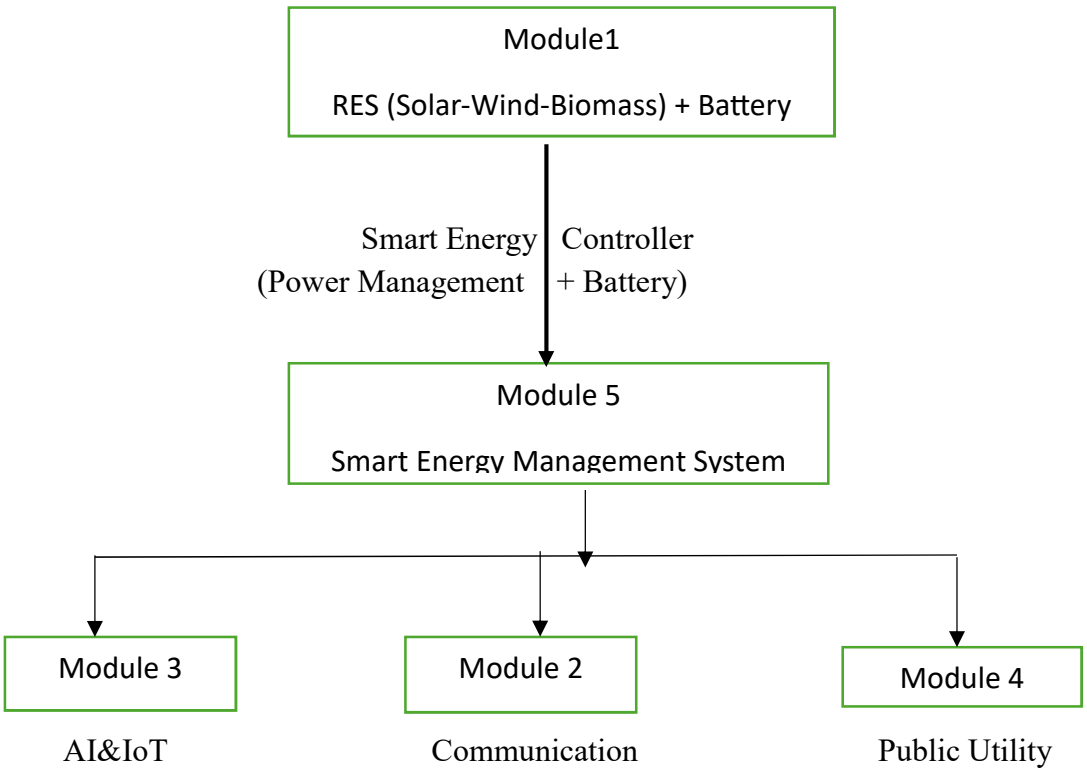

Fig 4: Architecture of Integration

Steps by Degrees of Integration

Module 1: This module is the main source of power generation and all the others module is totally dependent on it for their smoothy operation. Here we have three different RES of power generation which continuously generate power without any interruption in all whether conditions which makes this tree a special one. The clean and green generated power is stored in battery and smart inverters and power management system distribute the power to all other modules according to their needs.

Module 5: This module is the spinal cord of the entire system. It plays a leading role after module 1 i.e (source of power generation). It has AI and IoT based sensors and controllers which sense, guide, function and operates that involve battery management system based on charging/discharging, enhance the system of load balance without wastage, priority based specific allocation of power, boost the power backup system. It decides and supplies power to all the three different modules (2,3 and 4)

Module 3: It is the brain of the entire system. Its main function is to collect the data from various sources of the tree and filters and send it to the cloud centre. The AI helps to runs and guide all the devices as per the needs. It also helps to monitor the whole system of the tree. IoT helps the data to be accumulated in cloud on real time basis.

Module 2: Its main function is to provide signals for communication, boost internet services. It transmits signals and data to the clods and receive back. It is the heart of the tree which provides various signal for communication.

Module 4: It is the user interface between system and users. It is guided with AI technology which helps it to take smart decision. It has surveillance system, Charging system for EVs, Traffic managements controls, Air purification, public addressing and others. Its senses, visualize, monitors and acts accordingly.

Structure of Overall Workflow

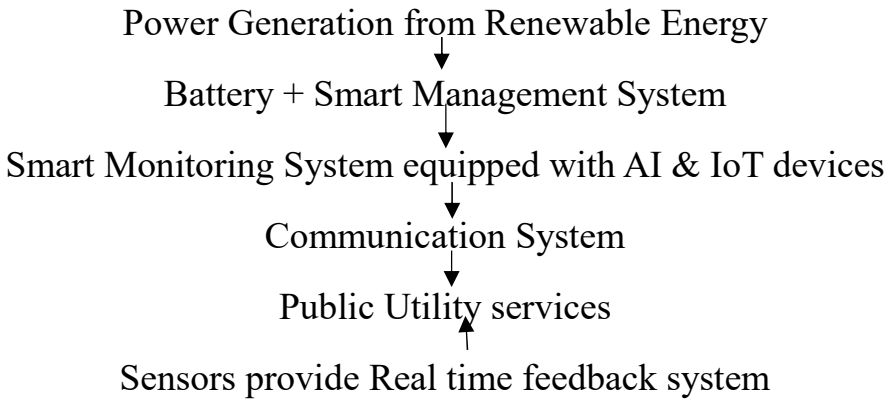

Fig 5: Overall Workflow Diagram

Fig 6: Overview of Panchamrit Tree

Efficiency calculated on the Basis of 24 Hours (00:00 – 24:00) Uses: For calculating its efficiency we have to consider the generation of power and consumption of it. As the tree is self-efficient system that govern Hybrid Renewable Energy System (HRES). The overall 24 hrs efficiency can be found out by comparing the optimum utilisation of energy generated by services that the tree is providing to the integrated system within it.

Calculation:

Power Generated = Sum of power generated from Solar, Wind and Biomass sources

$(P_G) = \sum (P_{solar} + P_{wind} + P_{Biomass})$

Power Consumed (P_C) = ∑ Power consumed by various equipment installed for providing services

Power Losses (P_L) = ∑ System losses

Therefore, Efficiency (η) = $\sum (P_C) / \sum (P_G)$

$$= \frac{\sum \text{Power consumed by various equipment installed for providing services}}{\sum (P_{Solar} + P_{Wind} + P_{Biomass})}$$

Percentage of efficiency, η % = $\sum (P_C) / \sum (P_G) \times 100$

Hence, the efficiency can also be found out in term of energy consumption

Efficiency = Energy Consumed / Energy Generated

$\eta = \sum E_C / \sum E_G$

Thus, Percentage of efficiency = (Energy Consumed / Energy Generated) × 100

$\eta\% = \sum E_C / \sum E_G \times 100$

Sr.No.	Different RES types for power generation	Supposed Value
1	Solar	18 Kwh/Day
2	Wind	12 Kwh/Day
3	Biomass	10 Kwh/Day
4.	**Total energy generated**	**40 Kwh/Day**

Table 3: Energy Generated in Kwh/Day

Sr.No.	Consumption of energy by various integrated sources	Assume Value
a.	All energy consumable sources which are integrated in it	36 Kwh/Day

Table 4: Energy Consumption in Kwh/Day

System losses = 04 Kwh/Day i.e. Energy losses in system

Thus, a practical assumption-based analysis for finding out the efficiency of Panchamrit Tree may be calculated as:

$\sum E_G = 40$

$\sum E_C = 36$

Efficiency = Total Energy Consumed / Total Energy Generated

That is $\eta = \sum E_C / \sum E_G$

So, $\eta\% = \sum E_C / \sum E_G \times 100 = (36 \div 40) \times 100 = 90\%$

Time taken to find the overall efficiency on 24 hrs basis (00:00 – 24:00)

Here Kwh /Day = Kilowatt hour per day

Thus, Total Energy Generated = Total Energy Consumed + Total Energy Losses in System

$P_G = P_E + P_L$ i.e.

40 Kwh /Day = 36 Kwh /Day + 4 Kwh /Day

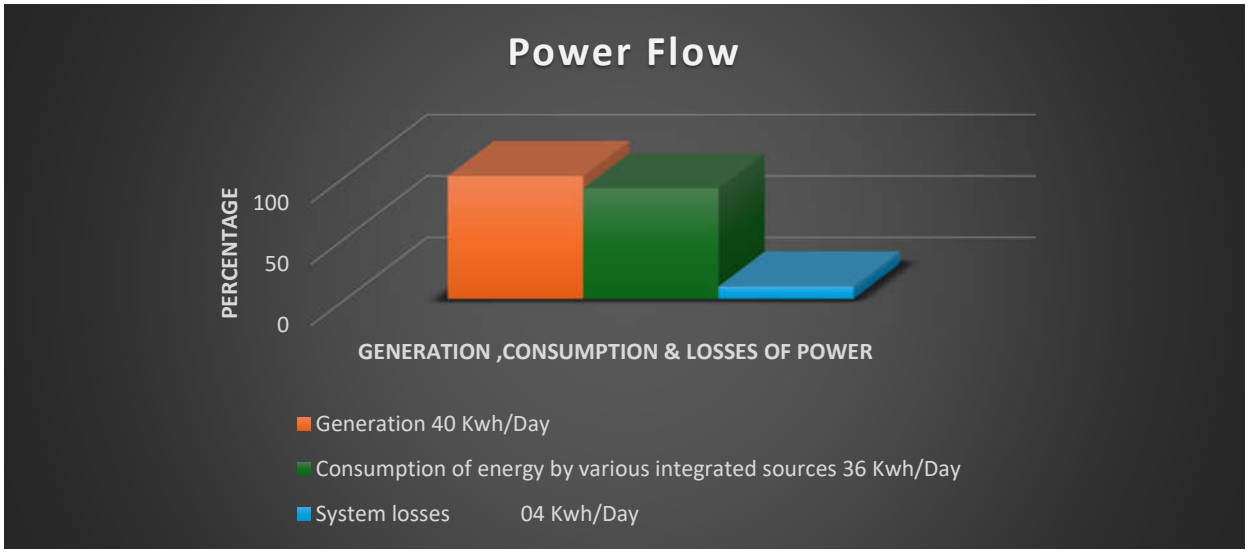

Fig 7: Power flow

Power generated by Hybrid Renewable Energy System (HRES) depending of various whether condition as assumed i.e. from Solar - 04KW + Wind - 04KW (0.5×8) + Biomass prototype on daily basis.

Sr.No.	Season	Solar (kwh/day)	Wind (kwh/day)	Biomass (kwh/day)	Total (kwh/day)
1.	Summer	24	06	10	40
2.	Monsoon	09	21	10	40
3.	Winter	18	12	10	40

Table 5: Energy Generated in Kwh/day in different season

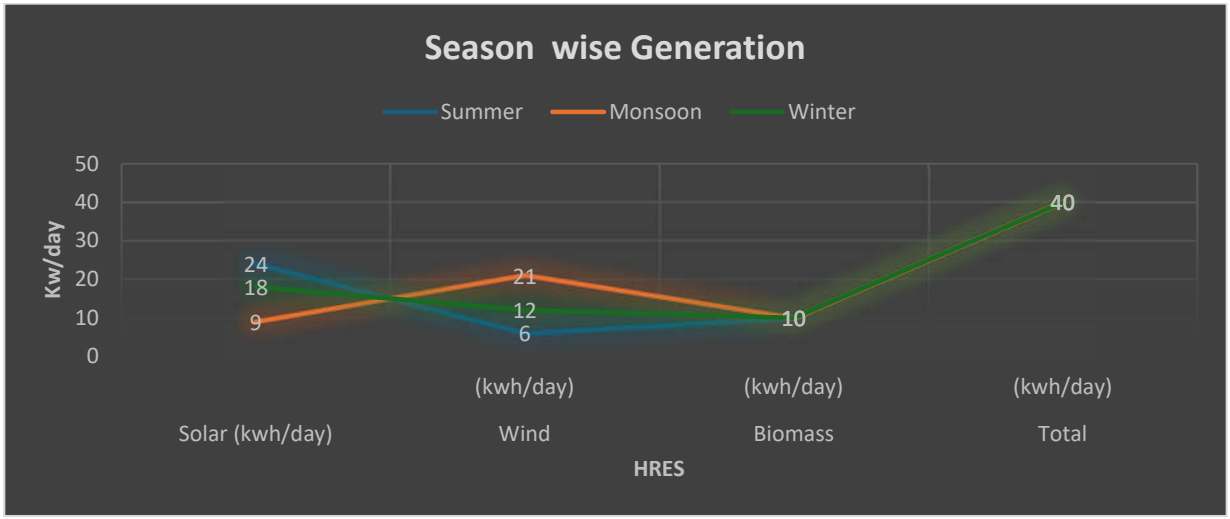

Fig 8: Season wise HRES power generation

Characterstics: This modern tree design is a live example in the field of engineering. It has combined various branches of engineering under a single structure. It is equipped with various technologies. Here SAPS is used in the form of RE which generate power so it is self-dependent cum self-driven tree which itself generate power for its own. It produces clean and green energy. The residue from biomass can be used as an organic fertilizer for cultivation of crops. The smart power and battery management system helps to maintain the efficiency of this tree. The IoT based sensors helps to gather, collect and transmit data on real time.AI based sensor helps in power distribution, predictive maintenance and other works. The communication system helps to communicate the things. The public utility equipment helps to address and alerts the public whenever needed. The Air purification system clean the area. It filters and settle down the dust particle having range from PM 2.5 to PM 10. Filters SOX mainly - Sulphur oxide (SO_2), NOX mainly – Nitrogen oxide (NO and NO_2) and also Carbon oxide mainly (CO and CO_2) and thus helps to improve the quality of the surrounding air. It also has EVs and mobile charging ports station powered by renewable energy system of power generation. A.I

based smart management system helps to prevents and overloads and increase the life spam of the battery. IoT based systems enable to monitors the status of charging even through far places on real time. The AI based sensors are used to sense the luminous level intensity and turn ON/OFF the street lighting system. The digital display system helps to aware the public regarding temperature, humidity and whether forecasting system. The smart traffic management system enhances the flow of traffic and reduce the jams and save times of all. The cameras help to keep close eyes on various nearby activities and continuous surveillance. This Panchamrit tree helps in reducing the road accidents and servers as a life saver system.

Protection Devices Needed: This tree is equipped with various safety devices which provides protection and safety users interference. To protect the entire system various protection system that are installed in it are

- Lighting Protection System (LPS): This system is mainly used to protect the structure and various electronics devices or equipment from strikes that occurs during lighting.
- Earthing & Grounding System: This protects the users from getting electrical shock while operating the tree. It also ensures that fault currents can be grounded to the mother earth in case of any leakage or dissipation.
- Surge Protection Devices (SPD): This system is used to prevent the solar inverters, all the devices that are used for communication and sensors based on AI- IoT from surge voltage.
- Circuit Breakers (MCCB, MCB and ELCB or RCCB): These all types of protecting devices helps the system parts or circuits at different level of faults i.e.
    a) MCB (Miniature Circuit Breaker): – Used for individual circuits protection system
    b) MCCB (Moulded Case Circuit Breaker): – Used for providing protection in main power distribution system
    c) ELCB or RCCB (Earth Leakage Circuit Breaker or Residual Current Circuit Breaker): – Used to prevent the system from earth leakage faults
- Fuses – Used to protect from overcurrent in any from the supply current sources that is in the form of AC (Alternating Current) or DC (Direct Current)
- BMS (Battery Management System) – Used to monitor health condition of the battery
- Switches – Used to switch ON/OFF the individual circuits
- E-Stop (Emergency Stop) Devices – Used to shuts down or stop the complete operating system immediately during emergency
- Sensors – The different types of sensors are used for prevent the system from following situation that may occurs during operation i.e.
    a) Temperature Sensor: - To sense and monitor the level of temperature of various devices installed in the system from overheating (batteries, biomass chambers and electrical panels)
    b) Pressure Sensor: - To sense and monitor the pressure level of windmills and biomass chambers
    c) Gas Leakage Sensor: - Its main function is to sense and monitor the leakage of gases from biomass chambers

- Relays: - Used to prevent the system from abnormal condition of voltage or current
- IoT and A.I Fault Detection based System: - This system is mainly used to prevent and send alerts to the control unit.
- Fire Protection Devices: - This system sense, monitor and protect the system in case of fire or smoke
- IPs Protections: - Indicate the level of Ingress Protection used in the system i.e. IP65 or IP66 type

Scope: The Panchamrit tree has a bright scope in near future. It is equipped with various technologies under single stage. It can be installed in various such as in the centre of junction of roads, railway station, market places, bus stands and other busy places. It is a smart tree that can mainly be used in smart cities and have a future ahead in urban, semi urban and rural places that is across PAN area of the entire country. It targets to provide an upper hand in the infra process of urbanization while utilizing less space and supporting clean and green campus. It has all the systems which generate, provide various services in a cohesive single system. It helps in surveillance system which boost safety while providing real time data. It proves to be a high assist system which has multipurpose uses.

Limitation: The design and method of assembling cum integrating various technology-based modules under a single system is really a challenging task which required high skills for operation. The integrate all the five modules for successful operation may faces many complexities. The mainly problem that one can faces is synchronizing the whole system. Another limitation may be face that is if any fault occurs then to find it the entire system has to be turn off. The size, place and other condition always vary from place to place and every time we have to change the design accordingly. The generation of power may vary due to various whether condition in different places. The efficiency of air purification system may face various according to the condition where it is installed for operation. Overall, the fusibility of the Panchamrit tree may be justified on practical application of its uses in various conditions.

Conclusion: The Smart Panchamrit Tree is self-functioning human crafted tree which is built with the combination of various field of engineering. It has smart intelligent based infrastructure with beautiful architecture. It has various system which are integrated together to work in a most effective way to redefine and restructure the nature. It has a smart energy management system which keep close eyes on power production, distribution and utilization to its full extent. It has three different system of generating clean and green energy, good communication system, high internet connectivity, Wi-Fi based system, Air purification system, public utility and addressing system, Intelligence traffic management system, surveillance system, IoT based sensors for monitoring, AI sensors for predictive maintenance system, Battery banks for storage. Overall, it is useful to manage the system with good governance which minimises road congestion with high safety and reduces accident. It also helps in reducing pollution and promote high standard index of living in a smart automated system. It helps in making healthy environment and stands as an ideal cum unique one point solution for future smart cities with fast and smooth mobility along with neat, green and clean campuses

References:

1. Development of an indoor air purification system to improve system to improve ventilation and air quality, G.Swamy Heliyon,2021
2. An IoT Based Air Pollution Monitoring System for Smart Cities, Harsh Gupta; Dhananjay Bhardwaj; Himanshu Agrawal; Vinay Anand Tikkiwal; Arun Kuma, IEEE Conference,2019
3. Green Energy Generation: A massive Challenge, Shantanu Virnave, International Journal of Research in Engineering Technology, Vol 9, Issue 6, pp 1-10,12/2024
4. C. Kaiwen, et al. "An Intelligent Home Appliance Control-based on WSN for Smart Buildings", *In the Proceedings of the IEEE International Conference on Sustainable Energy Technologies (ICSET)*, Hanoi, Vietnam, 14-16 November 2016, pp. 282–287.
5. Energy Resources need Balanced Utilization, Shantanu Virnave, The Academics International Journal of Multidisciplinary Research, vol 2, Issue 4, pp 224-234,04/2024
6. Optimal design of Hybrid Renewable Energy System (HRES) for Off Grid Application in Remote Areas, Shantanu Virnave, Sanjay Jain, Shodh Sangam, Vol 4, Issue 06, pp 92-98,12/2021
7. A smart AI-based solution for traffic management, Kiran Kumar, Satyam Rai, Shatakshi, Subharata Hore, Recent Trends in Intelligent Computing and Communication,2025,CRC Press,1st Edition
8. Latest Scenario of World Energy Demand, Electricity Consumption and Their Development Trend, Shantanu Virnave, Sanjay Jain, Research Journal of Engineering Technology and Medical Sciences, Vol 4, Issue 04, 12/2021
9. Non-Conventional Energy Sources, Book by G.D.Rai, Khanna Publication,2001
10. Principles of Communication Engineering, Book by Anokh Singh and A.K.Chhabra ,S.Chand Publivation,2004
11. Communication Engineering, Book by J.S.Chitode, Technical Publications Pune,2006
12. Energy Management,Book by W.R.Murphy and G. Mcaky, Elsevier,2018
13. Artificail Intelligence,Book by Russell,3rd Edition,Pearson,2015
14. Internet of Things & Internet of Energy, Book by Dr.Prattek Nigam, Shantanu Virnave and Jonnalagadda Pavan,1st Edition, AGPH Books,2022
15. Design of Antenna for multipurpose wireless Communication: Microstrip Antenna,ShantanuVirnave, International Journal of Science and Research,Vol 13,Issue 5, pp 1-5,05/2024
16. Frances Moore, "Climate Change and Air Pollution: Exploring the Synergies and Potential for Mitigation in Industrializing Countries", Sustainability*, 2009*. Vol. 1, pp. 43–54.
17. Smart Surveillance Systems: Trends, Challenges and Future Directions, Glen Moepi, The Indonesian Journal of Computer Science,2025.
18. Emerging trend in smart technology for sustainability,Surveillance of CCTVs using IoT devices, S. Yashaswini, M. G. Jayanthi, Shreekanth M. Prabhu, Handbook on Integrating Smart Technologies for Sustainable Development CRC Press ,2026

19. United Nations Framework Convention on Climate Change (UNFCCC). Paris Agreement.2015.Available,online: https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf (accessed on 5 January 2025).
20. Electric Mobility Innovation with Intelligence AI and Machine Learning Integration, Book by Shantanu Virnave, Book River Publication,2026
21. Haldia, P.; Kumar, S.; Negi, S.; Sagar, N. Reliability Improvement Technique Considering Various Renewable Energy Sources. In Proceedings of the IEEE International Conference on Industrial Electronics: Developments and Applications (INDUC 2023), Imphal, India, 18–22 August 2023; IEEE: New York, NY, USA, 2023; pp. 372–380.
22. Mokhtara, C.; Negrou, B.; Settou, N.; Settou, B.; Samy, M.M. Design optimisation of off-grid Hybrid Renewable Energy Systems considering the effects of building energy performance and climate change: Case study of Algeria. Energy 2021, 219, 119605
23. Council, E.V. Consumer Attitudes Survey 2021. 2021. Available online: https://electricvehiclecouncil.com.au/wp-content/uploads/2021/10/2021-EVC-carsales-Consumer-attitudes-survey-web.pdf (accessed on 5 April 2025).
24. Sawle, Y.; Jain, S.; Babu, S.; Nair, A.R.; Khan, B. Prefeasibility economic and sensitivity assessment of hybrid renewable energy system. *IEEE Access* 2021, *9*, 28260–28271.
25. Rahimi, I.; Nikoo, M.R.; Gandomi, A.H. Techno-economic analysis for using hybrid wind and solar energies in Australia. *Energy Strategy Rev.* 2023, *47*, 101092
26. Bhatt, A.; Ongsakul, W. Optimal techno-economic feasibility study of net-zero carbon emission microgrid integrating second-life battery energy storage system. *Energy Convers. Manag.* 2022, *266*, 115825.
27. Berman, J.J. (Ed.) Chapter 4—Understanding Your Data. In *Data Simplification*; Morgan Kaufmann: Boston, MA, USA, 2016; pp. 135–187
28. Al, Ferdous, A. S. A., & Gupta, K. D. (2025). An Extensive and Methodical Review of Smart Grids for Sustainable Energy Management-Addressing Challenges with AI, Renewable Energy Integration and Leading-edge Technologies. IEEE Access, 1. https://doi.org/10.1109
29. Dawn, S., Ramakrishna, A., Ramesh, M., Das, S. S., Rao, K. D., Islam, M. M., & Ustun, T. S. (2024). Integration of Renewable Energy in Microgrids and Smart Grids in Deregulated Power Systems: A Comparative Exploration. Advanced Energy and Sustainability Research, 5(10), 2400088. https://doi.org/10.1002/aesr.202400088
30. Dhanushkodi, K., & Thejas, S. (2024). AI Enabled Threat Detection: Leveraging Artificial Intelligence for Advanced Security and Cyber Threat Mitigation. IEEE Access, 12, 173127–173136. https://doi.org/10.1109/ACCESS.2024.3493957
31. Huang, T., Zhang, Q., Tang, X., Zhao, S., & Lu, X. (2022). A novel fault diagnosis method based on CNN and LSTM and its application in fault diagnosis for complex systems. Artificial Intelligence Review, 55(2), 1289–1315. https://doi.org/10.1007/s10462-021-09993-z
32. Kiasari, M., Ghaffari, M., & Aly, H. H. (2024). A Comprehensive Review of the Current Status of Smart Grid Technologies for Renewable Energies Integration and

Future Trends: The Role of Machine Learning and Energy Storage Systems. Energies, 17(16). https://doi.org/10.3390/en17164128

33. Mohanty, A., Ramasamy, A. K., Verayiah, R., Bastia, S., Dash, S. S., Cuce, E., Khan, T. M. Y., & Soudagar, M. E. M. (2024). Power system resilience and strategies for a sustainable infrastructure: A review. Alexandria Engineering Journal, 105, 261–279. https://doi.org/10.1016/j.aej.2024.06.092
34. Pandiyan, P., Saravanan, S., Usha, K., Kannadasan, R., Alsharif, M. H., & Kim, M. K. (2023). Technological advancements toward smart energy management in smart cities. Energy Reports, 10, 648–677. https://doi.org/10.1016/j.egyr.2023.07.021
35. Perera, A. T. D., & Kamalaruban, P. (2021). Applications of reinforcement learning in energy systems. Renewable and Sustainable Energy Reviews, 137, 110618. https://doi.org/10.1016/j.rser.2020.110618
36. Rahman, M. M., Dadon, S. H., He, M., Giesselmann, M., & Hasan, M. M. (2024). An Overview of Power System Flexibility: High Renewable Energy Penetration Scenarios. Energies, 17(24). https://doi.org/10.3390/en17246393
37. Rajkumar, V. S., Stefanov, A., Presekal, A., Palensky, P., & Torres, J. L. R. (2023). Cyber Attacks on Power Grids: Causes and Propagation of Cascading Failures. IEEE Access, 11, 103154–103176. https://doi.org/10.1109/ACCESS.2023.3317695
38. Rehmani, M. H., Reisslein, M., Rachedi, A., Erol-Kantarci, M., & Radenkovic, M. (2018). Integrating Renewable Energy Resources into the Smart Grid: Recent Developments in Information and Communication Technologies. IEEE Transactions on Industrial Informatics, 14(7), 2814–2825. https://doi.org/10.1109/TII.2018.2819169
39. Sharma, N., Acharya, A., Jacob, I., Yamujala, S., Gupta, V., & Bhakar, R. (2021). Major Blackouts of the Decade: Underlying Causes, Recommendations and Arising Challenges. 2021 9th IEEE International Conference on Power Systems (ICPS), 1–6. https://doi.org/10.1109/ICPS52420.2021.9670166
40. Patel, A.; Swathika, O.G.; Subramaniam, U.; Babu, T.S.; Tripathi, A.; Nag, S.; Karthick, A.; Muhibbullah, M. A Practical Approach for Predicting Power in a Small-Scale Off-Grid Photovoltaic System using Machine Learning Algorithms. Int. J. Photoenergy 2022, 2022, 9194537.
41. Gupta, V.; Sharma, M.; Pachauri, R.K.; Babu, K.D. A low-cost real-time IOT enabled data acquisition system for monitoring of PV system. Energy Sources Part A Recovery Util. Environ. Eff. 2021, 43, 2529–2543
42. Spanias, A.S. Solar energy management as an Internet of Things (IoT) application. In Proceedings of the 2017 8th International Conference on Information, Intelligence, Systems & Applications (IISA), Larnaca, Cyprus, 27–30 August 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–4.
43. Rathore, N.; Panwar, N.L.; Yettou, F.; Gama, A. A comprehensive review of different types of solar photovoltaic cells and their applications. Int. J. Ambient. Energy 2021, 42, 1200–1217
44. Dhiaa Jumah, Prof. Dr. Omer K. Ahmed, Prof. Dr. Shahab A. Abdulla, Recent Advances in Low-Speed Wind Turbines: A Critical Review , NTU Journal of Renewable Energy: Vol. 10 No. 1 (2026)

45. Singh, S.K.; Singh, M.; Singh, D.K. Routing protocols in wireless sensor networks—A survey. Int. J. Comput. Sci. Eng. Surv. (IJCSES) 2010, 1, 63–83
46. A New Secure Chaotic Communication System, Goutam Kuamr, A. Surywanshi,Computer Science,2015,Corpus Id 40494714
47. Joshi, P.; Raghuvanshi, A.S. Hybrid approaches to address various challenges in wireless sensor network for IoT applications: Opportunities and open problems. Int. J. Comput. Netw. Appl. 2021, 8, 151–187.
48. Priyadarshi, R. Energy-Efficient Routing in Wireless Sensor Networks: A Meta-heuristic and Artificial Intelligence-based Approach: A Comprehensive Review. Arch. Comput. Methods Eng. 2024, 31, 2109–2137
49. Chakraborty, R.S.; Mathew, J.; Vasilakos, A.V. Security and Fault Tolerance in Internet of Things; Springer: Cham, Switzerland, 2019
50. Agarkar, P.T.; Chawan, M.D.; Karule, P.T.; Hajare, P.R. A comprehensive survey on routing schemes and challenges in wireless sensor networks (WSN). Int. J. Comput. Netw. Appl. (IJCNA) 2020, 7, 193–207
51. Poornima, M.; Vimala, H.; Shreyas, J. Holistic survey on energy aware routing techniques for IoT applications. J. Netw. Comput. Appl. 2023, 213, 103584.