Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Design of Hybrid System for Remote Area Electrification at Trishuli, Chhattisgarh, INDIA

Payal Deshpande[1*], Pragya Nema[2]

[1]Research Scholar, Department of Electrical and Electronics Engineering, Oriental University, Indore (M.P.)

[2]Supervisor, Department of Electrical and Electronics Engineering Oriental University, Indore (M.P.)

**nenepayal14@gmail.com*

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract:

Rural development depends on having an abundance of reasonably priced energy, but 50% of the world's population lacks power while 20% have limited availability. Inadequate power forces affluent people and companies to relocate to cities, leaving rural regions even more vulnerable, since 80% of the total population are living in low electrification of area. Although the effort is still difficult, governments, non-governmental organizations, private businesses, all have undertaken extensive rural electrification projects. Standalone systems and grid expansion are common strategies. An emphasis on a hybrid model combining grid expansion with local renewable energy production, this research offers state-of-the-art methodologies for developing technically sound and economically viable solutions in a village named Trishuli in Chhattisgarh State. According to the simulation findings, in most cases, the hybrid solution is the least expensive method of action. It offers a sustainable, dependable, and profitable way to close rural energy shortages and promote long-term growth.

Keywords: *Homer Pro, PV, Battery, UltraCapacitor MIC, ANFIS Controller.*

Introduction

In rural areas, even though electrical grids are available, the supply is insufficient [1]. As per Indian development survey 2005 data, 11 states had more than 10 hours of power outages per day on average. According to more recent survey covering 240 villages, and 1920 respondents spread across India following analysis nh6as been done and concluded that 36% of rural households receiving supply from grid receive an electrical supply for more than 20h per day, only 44% receive an electrical supply for more than 16h per day, and 30% receive an electrical supply for less than 12h per day [2]. Another survey conducted in rural areas in India over 2083 household [3], reported an average number of hours supply per day of less than 6, and close to five days a month without any electricity. More than 80% of people were reported to be very dissatisfied with both the number of hours supply and regularity of service.

1.1 Remedial Solution to Overcome Power Outrages:

Distribution grids are already stretched beyond their rated capacity. This is one of the reasons for the frequent power interruptions during peak hours and in general, of the improper distribution and reliability of electrical supply in rural areas [4][5]. Many villages are situated far from the grid or in areas where they are difficult to access. The required investments in grid reinforcement or extension may be very high compared to the low consumption level of a newly electrified village. In addition, power thefts and low metering levels in rural areas have led to poor financial health for utilities that are not ready to invest in new infrastructures [6]. The International Energy Agency (IEA) predicted that mini-grids and off-grid systems will account for 70% of future rural electrification owing to the high operating and maintenance costs associated with grid extensions to remote locations [7]. Therefore, the easiest way to electrify rural areas is to extend the grid, which will solve all these concerns. Developing nations often employ centralized generation, extension of the main grid, or the development of standalone microgrids.

2.1. Feasibility of Site Selection and its implementation:

The common steps taken into consideration in the normal procedure of rural electrification include:

The load is first calculated by looking at how much power other nearby electrified villages use, as well as by looking at the residents' individual demands and economic capabilities.

The next step is to undertake a technical feasibility study to determine the viability of extending the main grid and the practicality of using local resources in a standalone solution.

The third step is to determine which options are financially feasible by comparing their respective incentives and the main grid electricity tariff.

Finally, the best course of action should enhance societal welfare while remaining practicable, cost-effective, and efficient.

Social considerations and implementation challenges are also a part of successful rural electrification strategies [8][9], with off-grid electrification [10] finding that local ownership and engagement are essential.

2.2. Implementation at selected site:

A robust demonstrating device for optimizing and simulating hybrid energy networks, HOMER Pro (Hybrid Optimization of Multiple Energy Resources) is appropriate for distributed generation and microgrid operations. It simulates the transfer of energy and interconnections across a variety of situations, allowing investigators to assess the technical and fiscal viability of numerous system designs. To provide resilient architecture pursuant to unpredictability, the tool uses a sensitivity evaluation to evaluate the effects of factors like fuel prices, load changes, and availability of assets. Finding the best and most economic alternatives is aided by economic indicators such as Levelized Cost of Energy (LCOE) and Net Present Cost (NPC).

Above discussed method is used for the electrification at Trishuli village located in Balrampur district of Chhattisgarh State. The following diagram shows the necessary Hybrid PV/Hydro System designed in HOMER Pro to check its economic feasibility. Based on it optimized NPC and the annual cost of the system is mentioned in Table 1 and Table 2 respectively.

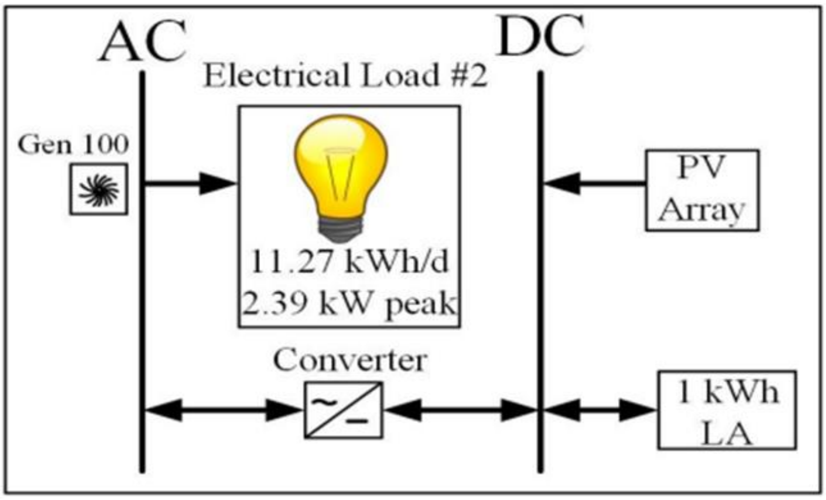


Fig. 1: - Hybrid PV/Hydro system diagram designed in HOMER Pro

Table 1: Optimized Net Present Costs of PV/ Hydro

Label	**Money**	**Functioning**	**Auxiliary**	**Retrieve**	**Assets**	**Aggregate**
Generic 1kWh Lead Acid	15610	6811	13980	-1874	0	34245
Generic flat plate PV	26,955	1,497	0	0	0	28,465
Generic Hydro 100kW	460847	178225	0	0	0	638,190
System Converter	803.78	0	342.25	-64.35	0	1,179
System	503393	185858	14300	-1925	0	701954

Table 2: Annualized Costs of PV/Hydro System

Label	**Money**	**Functioning**	**Auxiliary**	**Retrieve**	**Assets**	**Aggregate**
Generic 1kWh Lead Acid	1211	515	1044	-144.24	0	2648
Generic flat plate PV	2100	110.11	0	0	0	2200
Generic Hydro 100kW	35651	13768	0	0	0	49366
System Converter	62.32	0	26.55	-4.96	0	83.49
System	38752	14353	1102	-149.50	0	54298

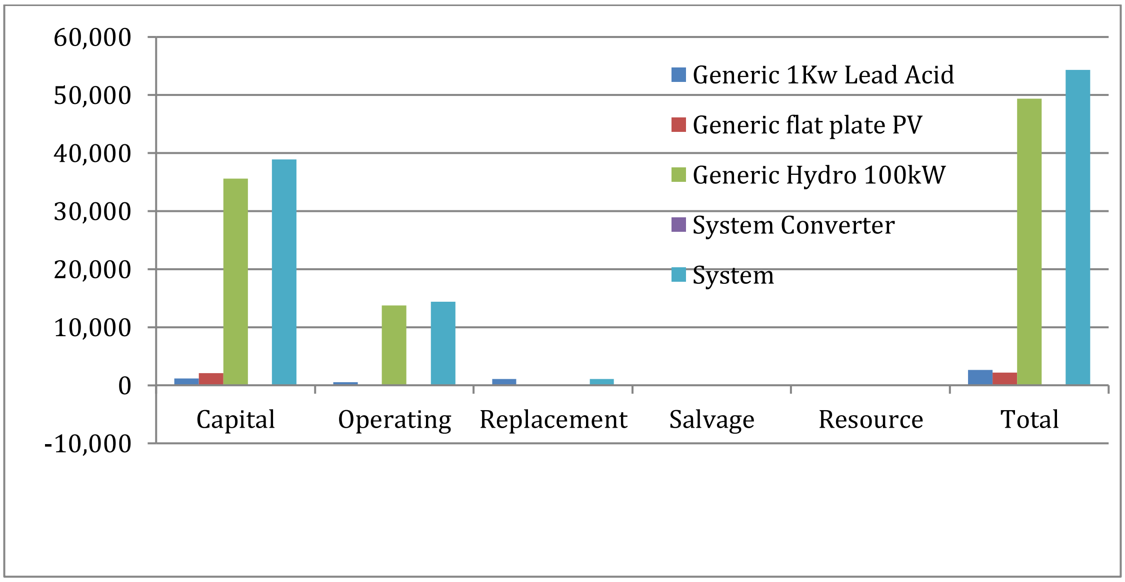


Fig 2: Graphical representation of Total Annualized Costs of PV/Hydro system

3. System Modelling

3.1 Converter Design

Depending upon the load side requirement, a novel MIC working in buck boost mode is designed. Different operation modes of Buck-Boost converter for independent switching pulses are given in Fig.3. In Buck-Boost mode for t_1, t_2, t_3, t_4, t_5, and t_6 input voltages V_{PV}, V_{BT}, V_{UC} and their combinations serve as input to the inductor in each case. For t_7 negative voltage appears across the inductor. Waveform for voltage and current across inductor in Buck Boost mode of operation is shown in Fig.4 & different working states are summarized in tabular form as shown below.

Table 3. MIC Stages in Buck-Boost Mode of Operation

Mode	**Conducting Switches**	**Active Source**	**Equation for V_L**	**Inductor Mode**
1	S_1, S_3, S_5	V_{PV}	$V_{PV} – 0$	Energy is stored
2	S_2, S_3, S_5	V_{BT}	$V_{BT} – 0$	Energy is stored
3	S_2, S_4, S_5	V_{UC}	$V_{UC} – 0$	Energy is stored
4	SS_1, S_3, S_5	$V_{PV} + V_{BT}$	$V_{PV} + V_{BT} - 0$	Energy is stored
5	SS_2, S_2, S_5	$V_{BT} + V_{UC}$	$V_{BT} + V_{UC} - 0$	Energy is stored
6	SS_1, SS_2, S_5	$V_{PV} + V_{BT} + V_{UC}$	$V_{PV} + V_{BT} + V_{UC} - 0$	Energy is stored
7	D_1, D_2	None	$-V_O$	Energy is released

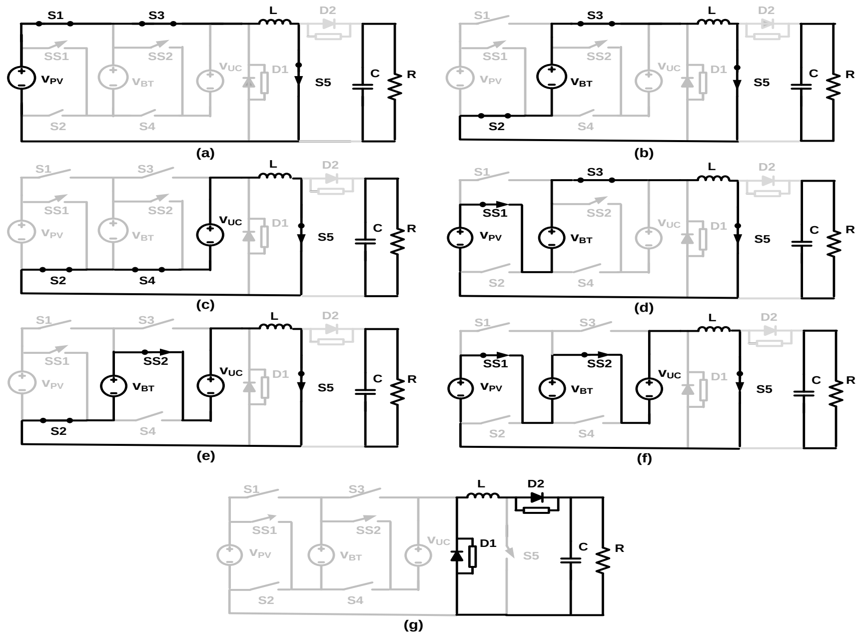


Fig. 3: Different Working Sates MIC (MIC Buck Boost Mode)

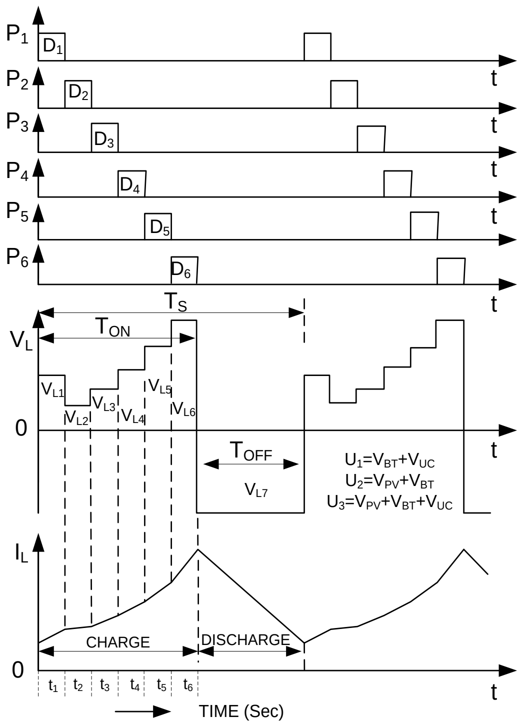


Fig. 4: Waveform of MIC in Buck-Boost mode for single switching cycle where, V_{L1}=V_PV: V_{L2}= V_UC: V_{L3}= V_BT: V_{L4}= U_1: V_{L5}= U_2: V_{L6}= U_3: V_{L7} = -V_O

3.2 Performance analysis of Buck boost converter:

The following methods are used to evaluate the values of parameters used in the circuit:

Based on principle of volt-second balance, average inductor voltage value can be calculated as:

$$\int_0^{T_s} v_L(t)dt = (V_{PV})t_1 + (V_{BT})t_2 + (V_{UC})t_3 + (U_1)t_4 + (U_2)t_5 + (U_3)t_6 + (-V_o)t_7$$

$$V_{PV}(t_1 + t_4 + t_6) + V_{BT}(t_2 + t_5 + t_6) + V_{UC}(t_3 + t_5 + t_6) - V_o(t_7) = 0$$

$V_o = \frac{V_{PV}D_{PV}+V_{BT}D_{BT}+V_{UC}D_{UC}}{(1-D_{PV}-D_{BT}-D_{UC})}$ …. (1)

here, $U_1 = (V_{PV} + V_{BT})$: $U_2 = (V_{BT} + V_{UC})$: $U_3 = (V_{PV} + V_{BT} + V_{UC})$

$$T_s = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7:$$

$$t_7 = t_{OFF}$$

$$Duty\ cycle\ of\ PV, \qquad D_{PV} = \frac{PV\ on\ time(t_1 + t_4 + t_6)}{T_s}:$$

$$Duty\ cycle\ of\ BT, \qquad D_{BT} = \frac{BT\ on\ time(t_2 + t_5 + t_6)}{T_s}:$$

$$Duty\ cycle\ of\ UC, \qquad D_{UC} = \frac{UC\ on\ time(t_3 + t_5 + t_6)}{T_s}$$

$$Therefore\frac{(t_7)}{T_s} = (1 - D_{PV} - D_{BT} - D_{UC})$$

Δi_Lwaveform and output voltage ripple Δv_c are used to calculate the parameter values to be connected in circuit. Therefore, Δi_L can be given as,

$$\Delta i_L = \left(\frac{U_{PV}}{L}\right)t_1 + \left(\frac{U_{BT}}{L}\right)t_2 + \left(\frac{U_{UC}}{L}\right)t_3 + \left(\frac{U_1}{L}\right)t_4 + \left(\frac{U_2}{L}\right)t_5 + \left(\frac{U_3}{L}\right)t_6 = -\left(\frac{V_o}{L}\right)t_7$$

here,

$$U_{PV} = V_{PV} - V_o: U_{BT} = V_{BT} - V_o: U_{UC} = V_{UC} - V_o$$

Solution for Δi_L yields

$\Delta i_L = \frac{V_o}{Lf_s}(1 - (D_{PV} + D_{BT} + D_{UC}))$ … (2)

Here, $f_s = \frac{1}{T_s}$

Therefore**,**

$L = \frac{V_o}{\Delta i_L f_s}(1 - (D_{PV} + D_{BT} + D_{UC}))$ … (3)

The above equation gives the value of Inductor.

Now for calculating the value of capacitors the capacitor charge balance method can be used

Considering the above waveform as snh6own in fig.4, for time duration t$_1$, t$_2$ and t$_3$: capacitor is charging and for time interval t$_4$ it is discharging.

So, the i_c for time interval t$_1$, t$_2$ and t$_3$ is given by

$$i_c = C\frac{dv_c}{dt} = I_o$$

Therefore, the slope of capacitor voltage is,

$$\frac{dv_c}{dt} = \frac{i_c}{C} = \frac{I_o}{C} = \frac{V_o}{RC}$$

Similarly, for time interval t4, the slope is,

$$\frac{dv_c}{dt} = \frac{i_c}{C} = \frac{I_L}{C} - \frac{V_o}{RC}$$

Based on principle of capacitor charge balance

$$\Delta v_c = slope \times length\ of\ slope$$

$$\Delta v_c = \frac{V_o}{RC} \times (t_{PV} + t_{BT} + t_{UC})$$

$$\Delta v_c = \frac{V_o}{RC} \times (D_{PV} + D_{BT} + D_{UC})T_s$$

$$v_c = \frac{V_o}{RCf_s} \times (t_{PV} + t_{BT} + t_{UC}) \qquad \ldots (4)$$

Here; $\Delta v_c =$ peak-to-peak voltage ripple

$$C = \frac{V_o}{R\Delta v_c f_s} \times (t_{PV} + t_{BT} + t_{UC}) \qquad \ldots (5)$$

The above equation gives the value of Capacitor.

3.3. Structure of ANFIS Controller

ANFIS is a mixed neuro fuzzy system that improves fuzzy inference systems (FIS) by adding the ability for neural networks to learn. This method modifies FIS MFs using input-output training data and learning algorithm. Thus, the ANFIS algorithm employs a mixed learning rule and manages complex nonlinear systems. The effectiveness of ANFIS in modifying FIS's membership functions has been broadly acknowledged.

Figure **5.18** illustrates the architecture of ANFIS controllers.

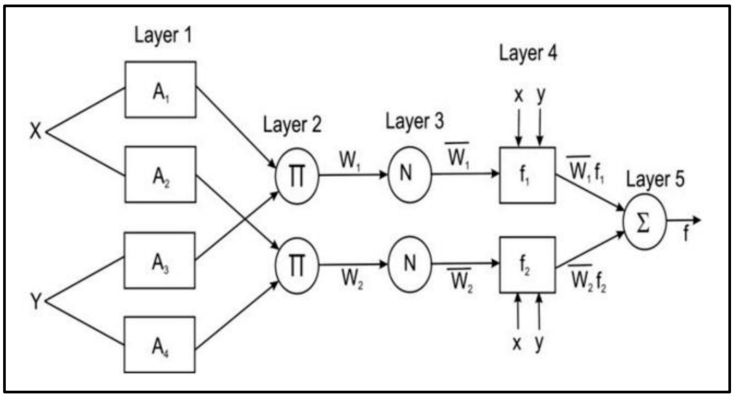


Fig. 5: Structure of the Back Propagation ANFIS

- **Layer 1 is Fuzzification Layer**: Here fuzzy membership functions (A1, A2, A3, A4, A5) are related to input variables (X, Y).
- **Layer 2 is Rule Layer** where the fuzzy rule' firing strength is considered by multiplying incoming signals.
- **Layer 3 is a normalization layer** that measures regulated rule strength using weights (W1, W2).
- **Layer 4 is Defuzzification Layer**, which forms fuzzy rules from input variables.
- **Layer 5 is a Summation Layer** displaying the ANFIS controller's output.

4. Simulations & Result Analysis

The proposed Novel- SRF Controller based Fuzzy ANFIS algorithm is compared with the standard algorithm used in ANFIS which has a fixed learning rate. Fig. 6 gives the initial learning rate for the required MFs.

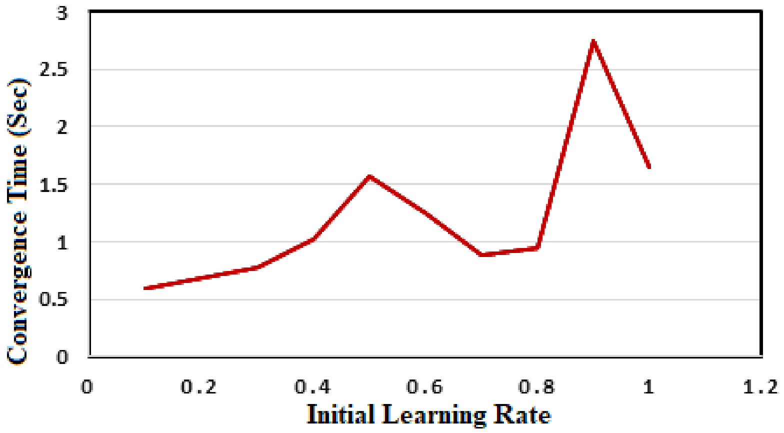
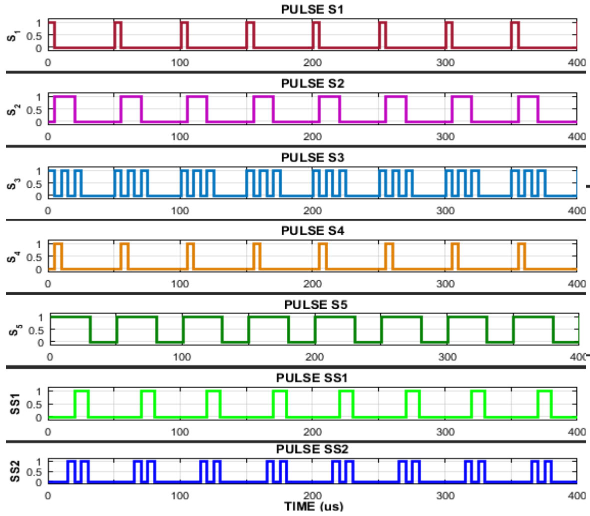


Fig. 6: - Time Convergence Graph



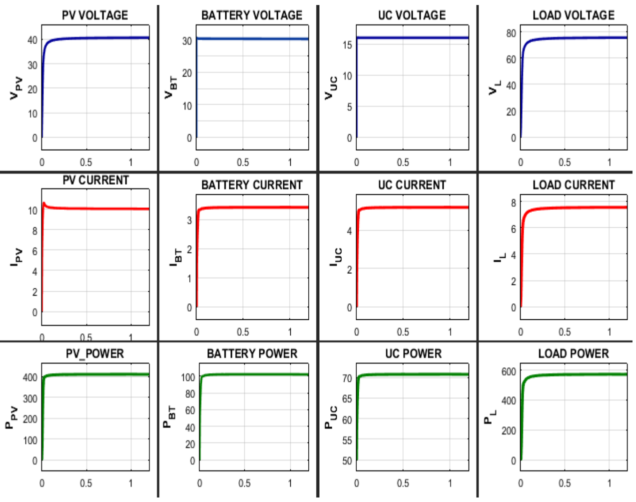


Fig.7: - Switching Pulses in Buck-Boost Operating Mode & Fig. 8: - RMS Analysis of V, I & P of PV, Battery, UC and Load in buck-boost mode

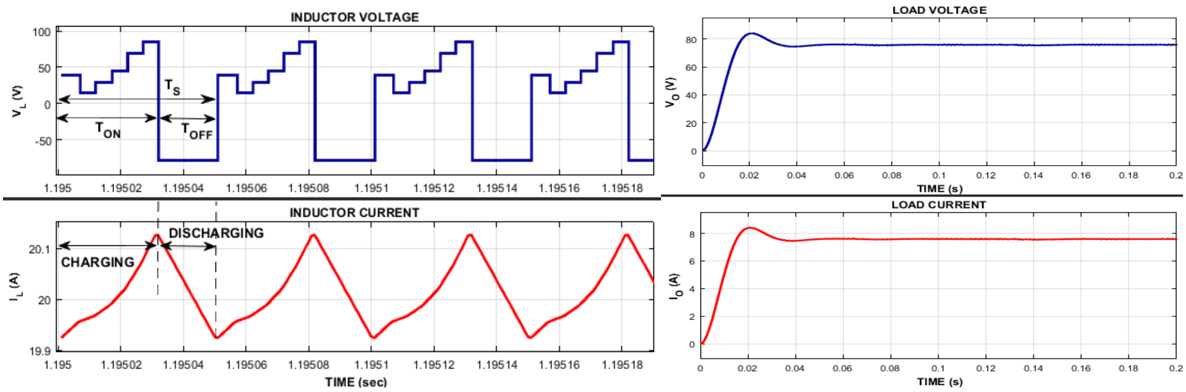


Fig. 9 & 10: - V_L & I_L ; V_0 & I_0 **Waveforms Buck-Boost Operating Mode**

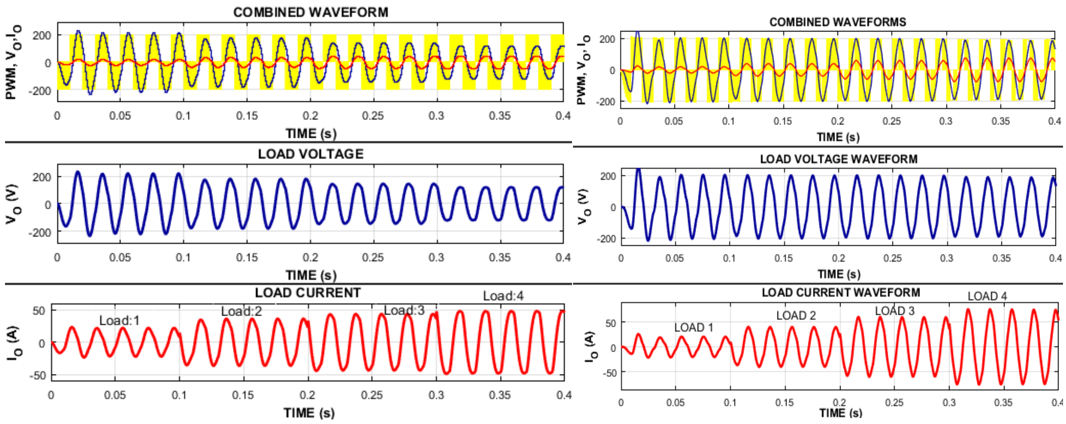


Fig. 11: - Uncontrolled Load V & I waveforms without controller & Fig. 12: Output V & I waveforms with ANFIS Controller

Different loads are applied at the simulation time of 0.1 sec., 0.2 sec., 0.3 sec. Fig.7 shows the input switching pulses in Buck-Boost mode. The loads are sequentially increased as can be observed by the waveform of current and RMS Analysis of V, I & P of PV, Battery, UC and Load can be seen in Fig. 8. Changes in inductor voltage and current and hence the changes in voltage and current across the load are observed as in Fig. 9 & 10. The last waveforms show the variation in final output voltage and current before the use of ANFIS controller and after the use of controller.

5. Conclusion

The results obtained from simulation work indicate the efficient working of the proposed control scheme. The above results show that for remote area electrification, the above discussed novel set up will prove to be a better option and can be further implemented for nonlinear load with discontinuous mode of conduction.

6.Funding

This research received no specific grant from any funding agency in the public, commercial, or non-for-profit sectors.

7.Conflicts Of Interest

The authors declare that there is no conflict of interest.

6. References

1. Almeshqab, F., & Ustun, T. S. (2019). Lessons learned from rural electrification initiatives in developing countries: Insights into technical, social, financial and public policy aspects. Renewable and Sustainable Energy Reviews, 102, 35–53. DOI:10.1016/j.rser.2018.11.035
2. Bose, D., Saini, D. K., Yadav, M., Shrivastava, S., & Parashar, N. (2021). Review of sustainable grid-independent renewable energy access in remote communities of India. Integrated Environmental Assessment and Management, 17(2), 364–375. DOI: 10.1002/ieam.4373
3. Chakravorty, U., Gupta, R., & Pelli, M. (2023). The economics of rural energy use in developing countries. In Handbook of Labor, Human Resources and Population Economics (pp. 1–21). Springer International Publishing.DOI: https://doi.org/10.1007/978-3-319-57365-6_248-1
4. Raj, S., Roodbar, S., Brinkley, C., & Wolfe, D. W. (2022). Food security and climate change: differences in impacts and adaptation strategies for rural communities in the global south and north. *Frontiers in Sustainable Food Systems*, *5*, 691191.https://doi.org/10.3389/fsufs.2021.691191
5. Shazdeh, S., Golpîra, H., & Bevrani, H. (2024). Advanced and smart protection schemes in renewable integrated power systems: A survey and new perspectives. Electric Power Systems Research, 235(110832), 110832. https://doi.org/10.1016/j.epsr.2024.110832
6. Bakhshi, R., & Sadeh, J. (2018). Economic evaluation of grid–connected photovoltaic systems viability under a new dynamic feed–in tariff scheme: A case study in Iran. Renewable Energy, 119, 354–364. https://doi.org/10.1016/j.renene.2017.11.093
7. Duran, A. S., & Sahinyazan, F. G. (2021). An analysis of renewable mini-grid projects for rural electrification. Socio-Economic Planning Sciences, 77(100999), 100999. https://doi.org/10.1016/j.seps.2020.100999
8. Sharma, H., & Mishra, S. (2019). Hybrid optimization model for smart grid distributed generation using HOMER. 2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), 94–99. **DOI:** 10.1109/RDCAPE47089.2019.8979121
9. Bakhshi, R., & Sadeh, J. (2018). Economic evaluation of grid–connected photovoltaic systems viability under a new dynamic feed–in tariff scheme: A case study in Iran. Renewable Energy, 119, 354–364. https://doi.org/10.1016/j.renene.2017.11.093Get rights and content
10. Oladigbolu, J. O., Ramli, M. A. M., & Al-Turki, Y. A. (2020). Optimal design of a hybrid PV solar/micro-hydro/diesel/battery energy system for a remote rural village under tropical climate conditions. Electronics, 9(9), 1491.**https://doi.org/10.3390/electronics9091491**
11. Sharma, H., & Mishra, S. (2019). Hybrid optimization model for smart grid distributed generation using HOMER. 2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), 94–99.**DOI:** 10.1109/RDCAPE47089.2019.8979121