Indonesian Journal of Electrical Engineering and Computer Science
Vol. 26, No. 2, May 2022, pp. 629~638
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v26.i2.pp629-638

Grey wolf optimization-recurrent neural network based maximum power point tracking for photovoltaic application

Arumbu Venkadasamy Prathaban, Dhandapani Karthikeyan
Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India

Article Info

Article history:

Received Oct 24, 2021
Revised Feb 21, 2022
Accepted Mar 16, 2022

Keywords:

Control algorithms
GWO-RNN
Hybrid MPPT
LUO converter
Photovoltaic system

ABSTRACT

To increase the photovoltaic (PV) power-generation conversion, maximum power point tracking (MPPT) is the primary concern. This works explains about the grey wolf optimization (GWO-RNN)-based hybrid MPPT method to get quick and maximum photovoltaic (PV) power with zero oscillation tracking. The GWO–RNN based MPPT method doesn't need additional sensor for measuring irradiance and temperature variables. The NLT is used for the multi-level inverter (MLI) control strategy to achieve less harmonics distraction and less switching losses with better voltage and current profile. This employed methodology brings remarkable aspects in the PV boosting potential extraction. A GWO–RNN controlled LUO converter is a zero-output harmonic agreement impedance matching interface that is MPPT is performed by placing the PV modules between the load regulator power circuit and the load regulator power circuit. To actualize the proposed hybrid GWO–RNN model for the PV system, perturb and observe, RNN, ant colony optimization, and artificial bee colony MPPT techniques are employed. The MATLAB interfaced dSPACE interface is used to finish the hands-on validation of the intended grid-integrated PV system. The obtained results eloquently support the appropriate design of higher-performance control algorithms.

Corresponding Author:

Dhandapani Karthikeyan
Department of Electrical and Electronics Engineering
SRM Institute of Science & Technology
Kattankulathur, Tamil Nadu, India
Email: karthipncl@gmail.com

1. INTRODUCTION

The photovoltaic (PV) system has made significant progress in recent years. Under the global power point tracking condition, maximum power point trackers (MPPTs) play a critical role in ensuring superior PV energy generation. Many MPPT control techniques are available, and they are used according on the applications. The fuzzy logic-based MPPT technique plays an essential role in this regard. It offers a simpler architecture and durable design that can tackle the PV power system's uncertainties and nonlinearity difficulties. Traditional there is discussion of MPPT procedures such as trouble and observe (T and O), hill climbing (HC), and increase of conductance (INC) [1]–[4]. T and O and HC approaches are easier to implement in hardware, but they include large oscillations close to the maximum power point (MPP), resulting in power losses. The increase of conductance approaches exacts and adaptable under a variety of atmospheric circumstances, and it also includes modelling and practical complexity. Under inconsistent solar irradiation and for the determination of right perturbation size, the aforementioned procedures are inefficient and traditional. Several research groups are aiming to reduce the cost, improve tracking, and increase the reliability of PV-based industrial sectors and applications. The main goal of hybrid techniques and methodologies is to reduce the amount of fuzziness and uncertainty in calculations. The proposed controller has been optimized offline utilizing hybrid techniques in this approach. The performance and effectiveness of hybrid techniques, which include the easiest control and easier execution under varied loading and defective operating situations, have been validated using simulation for the England 10-unit, 39 bus-based power systems. Despite the fact that we believe renewable energy sources are a transition to non-renewable energy sources, the efficiency of renewable energy sources is the key worry and an issue related to optimization difficulties and an emerging research field for academia [5]–[7].

Traditional MPPT methods and shortcoming are corrected using intelligent fuzzy logic controls (FLC) and artificial neural network (ANN) approaches as MPPT trackers under changeable weather conditions. In this regard, the fuzzy logic-based MPPT solution is critical because it has a streamlined architecture and robust design that can resolve PV (photovoltaic) power system uncertainties and nonlinearity damages [8]–[10]. The grey wolf optimization (GWO) and recurrent neural network (RNN) algorithm based maximum power point tracker (MPPT) will increase the system efficiency and performance by improving the tracking methods. The GWO is an innovative meta-heuristic technology. It is based on the principle of imitating the natural behavior of grey wolves. It is a large-scale search technique centered on three finest samples. The GWO algorithm gives innovative and new way to research oriented peoples [11]–[15]. The RNN is a substitute for a multilayer neural network. In the result, the RNN employs fewer hidden neurons since it includes a context layer for sustaining existing hidden neuron networks. As a result, the network is more reliable and can handle temporal patterns more efficiently. RNNs are a type of machine learning method that is best suited for sequential and continuous data, such as text, financial data, time series and other parameters. Especially the RNNs are ideal for solving the issues and concerns where the sequence is more precise than the individual items themselves. Hence, we need a continuous monitoring and sequential controls for the solar (photovoltaic) applications we are going for a GNN–RNN based hybrid methodology for a grid connected PV applications [16]–[18].

2. CURRENT SYSTEM TOPOLOGY

Figure 1 shows a block schematic of the existing system for photovoltaic maximum power point tracking (MPPT) and grid integration, the existing hybrid adaptive neuro-fuzzy inference system-particle swarm optimization (ANFIS-PSO)-based MPPT algorithm approach was used [19]–[22]. For control strategies and functions, the photovoltaic array was connected to the Zeta converter and the ANFIS–PSO based MPPT. It was employed with the three-phase voltage source inverter and proposed SVM HCC dSPACE. The Zeta converter is a fourth-order switching power converter that relies on two capacitors and two inductors. The Zeta converter delivers non-inverting results as compared to a buck or boost converter. It works in both continuous and discontinuous states, and the operating method of continuous operation is typically appropriate. The performance and efficiency of the hybrid ANFIS–PSO algorithm are compared to PSO, ACO, and artificial bee colony algorithm (ABC) algorithms over low/high solar isolation profiles and under partial shade situations. In comparison to existing PSO, ACO, and ABC algorithms that have been optimized, this scheme gives a rapid convergence velocity, zero steady-state error, less MPPT tracking period, and improved PV tracking efficiency and performance [23]–[25].

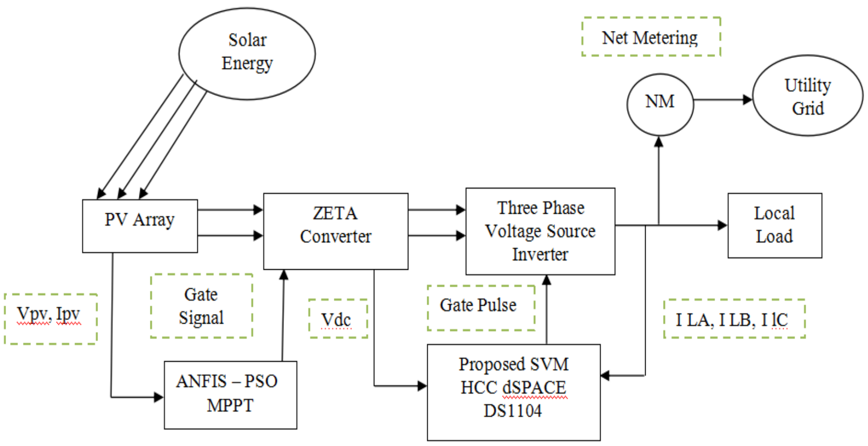


Figure 1. Block diagram of existing system

2.1. Existing work drawbacks

The existing MPPT device (ie) maximum power point tracking is lagging in speed up processes. Hence, if we want to go for a tracking device with increased speed means the system cost will also get increased. So, economically it’s not feasible for the PV applications [26]–[28]. The present MPPT’s doesn’t have the new tracking methods and the primary concerns with the converters are it has high ripple contents and the boosting performances of the converters were poor. The PWM generator is used to provide gate pulses. Thus, the active Pulse Width Modulation has higher harmonic losses and switching losses which lead to poor performance of the system with less efficiency & its equivalent circuit is shown in the Figure 2.

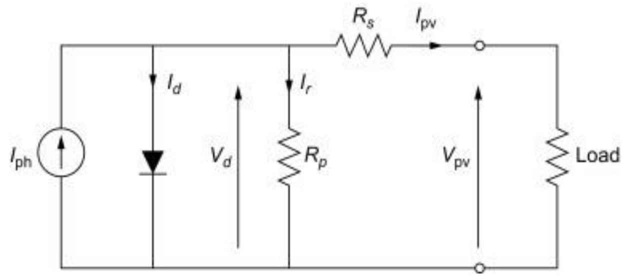


Figure 2. Equivalent PV cell model

2.2. Existing model simulation

This block diagram will show the GWO–RNN based photovoltaic system. The solar PV arrays will collect the solar radiations from the sun. The LUO converter is connected with PV arrays, in conjunction with maximum power point tracking (MPPT), are used to track the maximum power to linked systems in order to minimise system failures. The converter will help to reduce the ripple content since it has an internal filter with it. In this proposed system, we are using a grey wolf optimization (GWO)–recurrent neural network (RNN) based MPPT device to get high speed and improved tracking facilities. The RNN networks are different from the feed forward neural networks. RNNs will process and execute input sequences using their internal memory. To test the performance of the present system inverter, three inverters were simulated and their outputs were recorded, as shown in Figures 3-5.

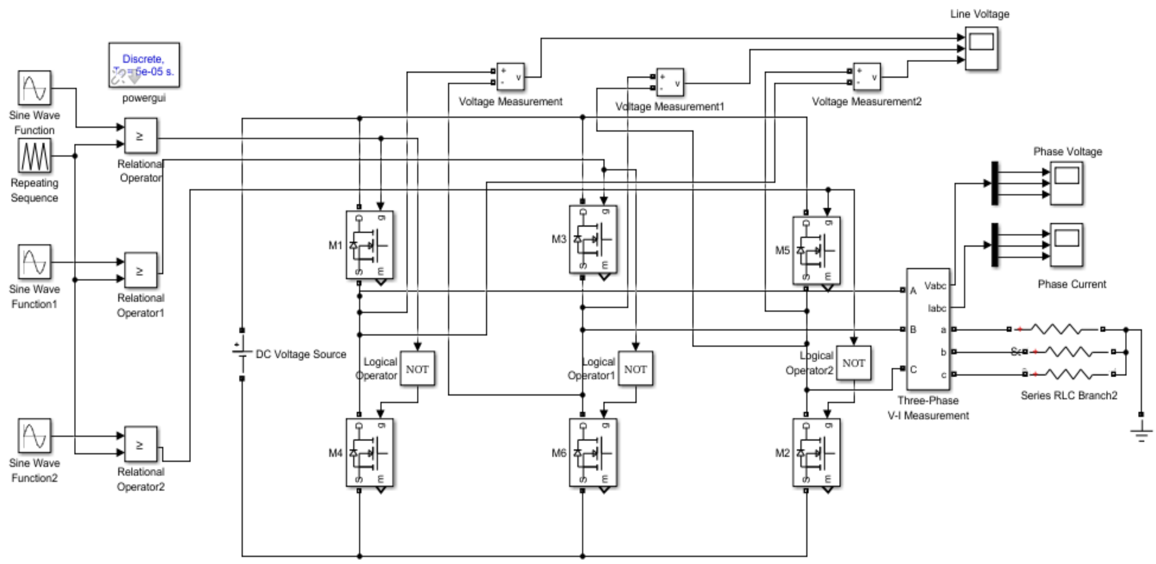


Figure 3. VSI simulation diagram

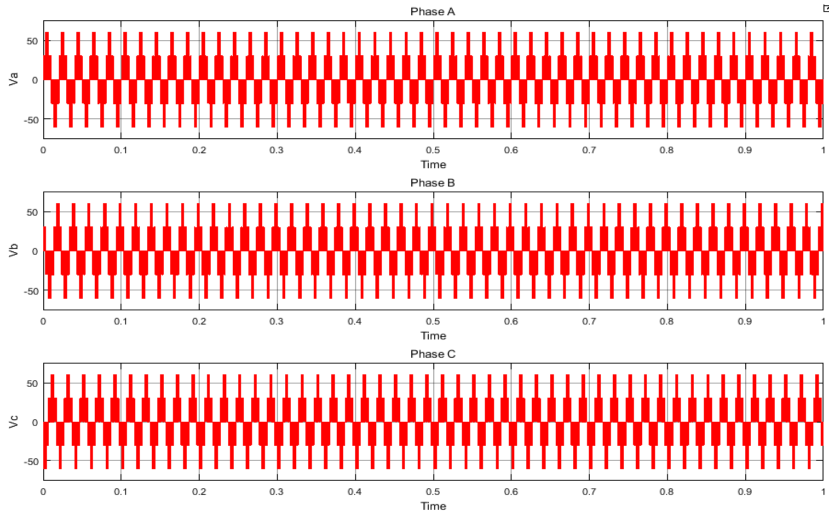


Figure 4. Three phase output voltage

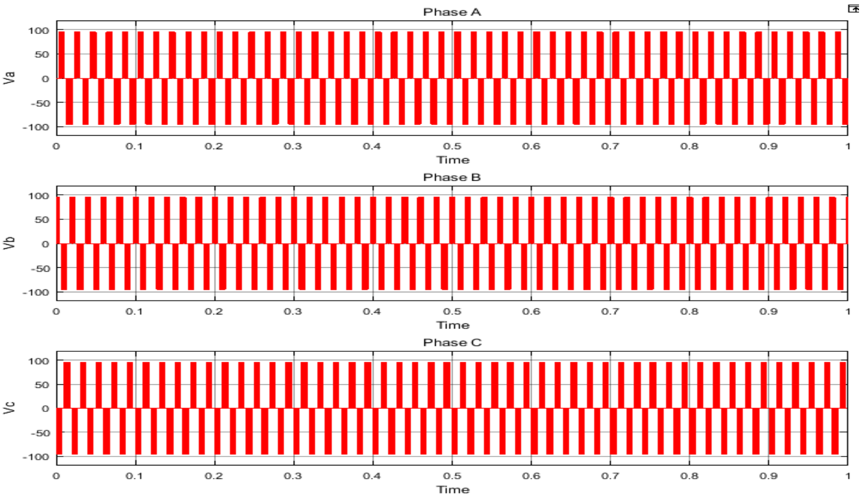


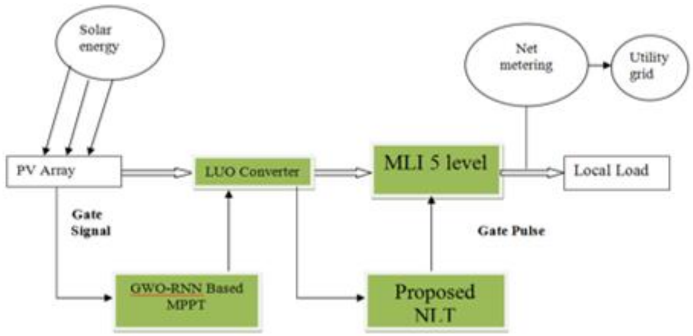
Figure 5. Three phase line voltage

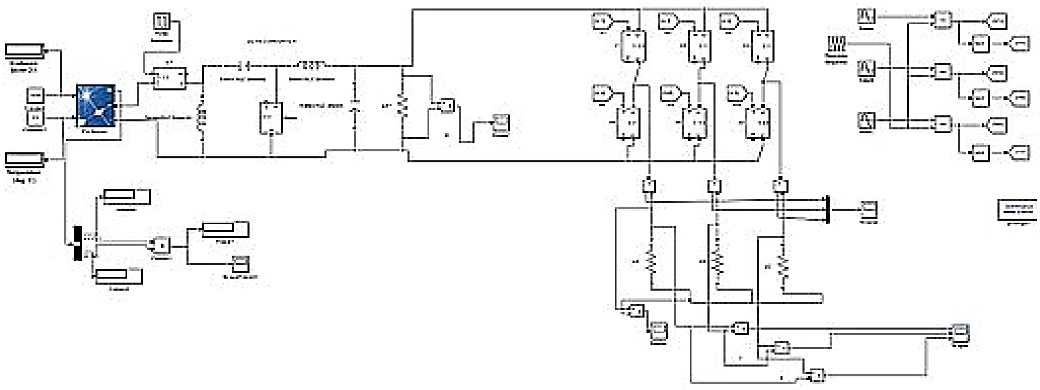
3. PROPOSED SYSTEM ANALYSIS

The Grey Wolf optimization or optimizer has turned up as an efficient meta-heuristic optimization method in both the performances as well as efficiency. It has a strong exploitation capability for unimodal problems and a stronger exploration capability for multimodal challenges. By avoiding local minima, it performs admirably for composite functions. The multi-level inverter (MLI) is connected in the system followed by the LUO converter to convert the dc voltage source into ac voltage source. Hence the converted ac source will be fed to the load and the utility grid according to the requirements and depends upon the applications.

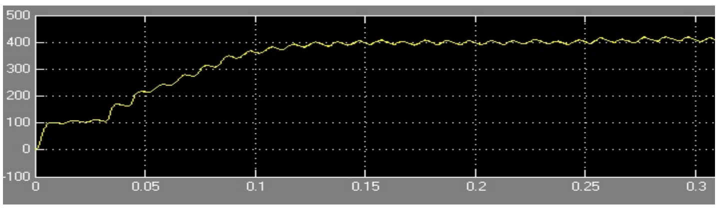
3.1. Proposed model simulation and results

The simulation model and the circuit diagram of the proposed GWO–RNN based system has been presented here. We have used MATLAB/Simulink tool for showcasing voltage source inverters circuit, LUO converter circuit and its waveforms. The grid connected voltage and current, the output power, voltage, current waveforms of the solar panels and the reactive power waveforms and also how they are performing in the system model and the existing Zeta converter system all have been extracted and showed here we use MATLAB/Simulink tool, model and output of Zeta converter, in a detailed form is given in Figure 6 as the proposed system block diagram, the Figure 6(a) as Zeta Converter simulation block and Figure 6(b) as simulation output of Zeta converter. The main objective of a three phase voltage source inverter, as previously stated, is to transform a constant DC voltage into a three phase AC voltage with variable amplitude and frequency.





(a)



(b)

Figure 6. Proposed system block diagram (a) Zeta converter simulation block, and (b) Simulation output of Zeta converter

The results of Zeta converter had proven that it’s not producing the expected output with this solar converter setup i.e. its output has more noise and the control of Zeta converter. To overcome this the proposed circuit model has been replaced with LUO converter where it can produce high efficient results which has been evidently shown in Figures (7-9) and its grid integrated results are represented below with the notification of Figure 10. Denotes the grid current waveform, Figure 10(b). Represents the grid voltage waveform and Figure 10(c). Pointout the grid vs frequency graph.

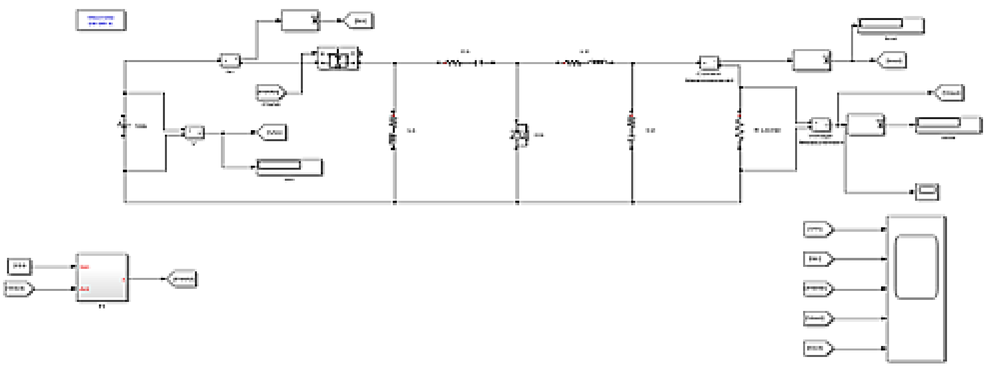


Figure 7. LUO converter simulation diagram

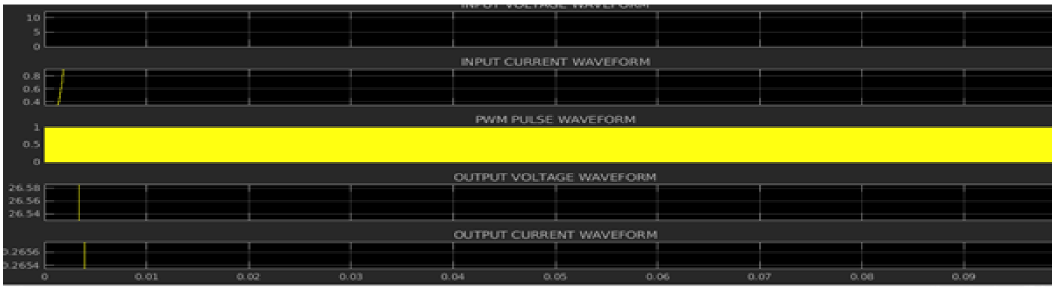


Figure 8. LUO converter input wavefor

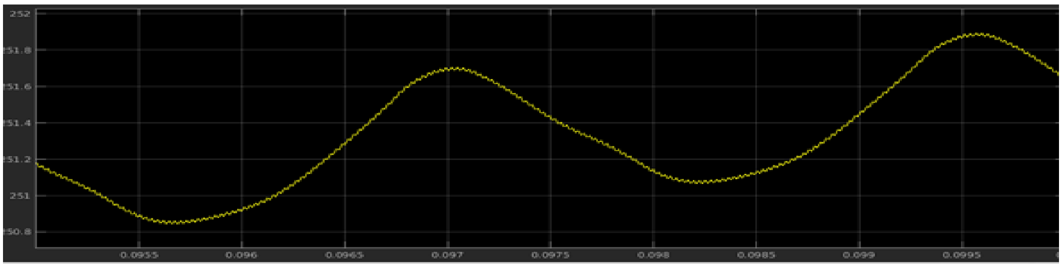
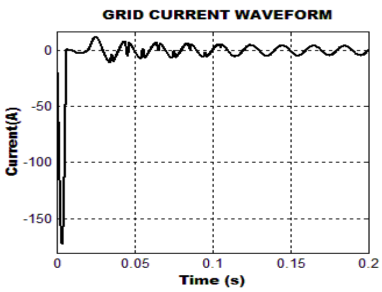
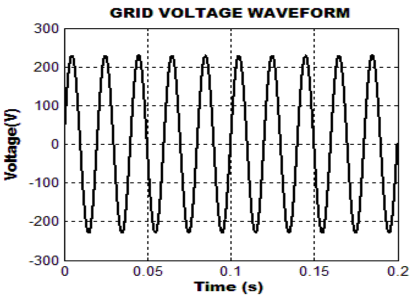


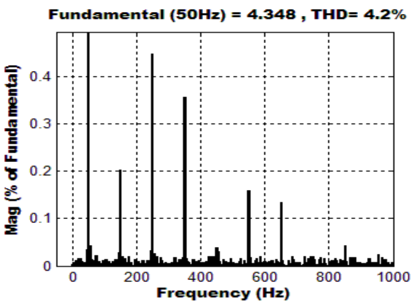
Figure 9. LUO converter output waveform



(a)



(b)



(c)

Figure 10. Grid integrated results (a) grid current waveform (b) grid voltage waveform, and (c) THD vs frequency graph

3.2. DC-DC converter voltage output waveform

Figure 11 denotes the various outputs of DC-DC converter of the proposed topology added with solar simulation output, which has been elaborated with subdivisions as shown in the Figure 11(a-g). The outputs are more evidently showing that it has a best performance compared to the existing system of Zeta converter with solar input the proposed RNN GWO algorithm increase the performance of MPPT tracking capacity.

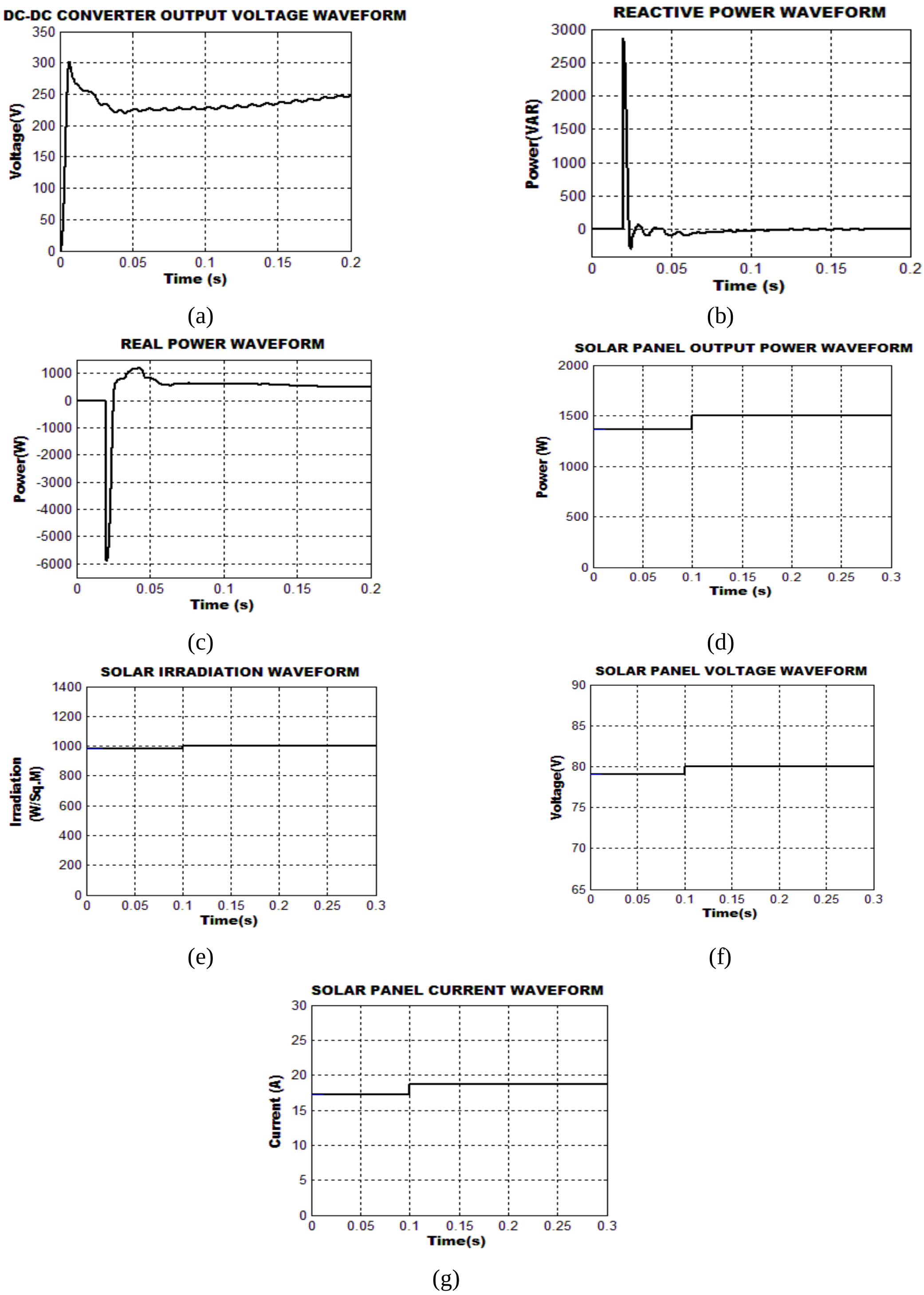


Figure 11. Represents the complete simulation results of solar outputs realted to various: a) DC–DC converter output voltage form, b) reactive power waveform, c) real power waveform, d) solar power waveform, e) solar irradiation waveform, f) solar voltage waveform, and g) solar current waveform

3.3. Multilevel inverter diagram

The inverter configuration was chosen to improve the performance of the proposed system has changed into a MLI where it can produce 7 level which has less THD high rate of voltage value which is exactly needed for the gird connected system the MLI circuits are shown in the Figure 12, followed by its switching states at Table 1 and the seven level simulation is visible at Figure 13.

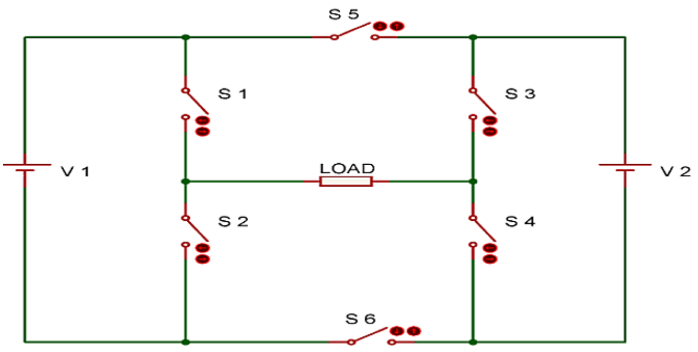


Figure 12. 7-level multilevel inverter

Table 1. 7-level multilevel inverter switching table

S1	S2	S3	S4	Sa	Sb	Digital
1	0	0	1	0	1	100
0	1	1	0	0	1	110
1	0	1	0	0	1	111
0	1	1	0	1	0	100
1	0	0	1	1	0	110
0	1	0	1	1	0	111

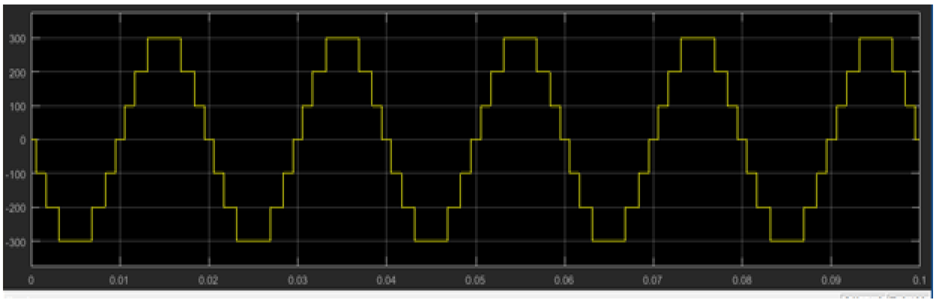


Figure 13. 7-level multilevel inverter output

4. HARDWARE RESULTS

The prototype of the proposed system has been shown in the Figure 14 which is exactly created as per the proposed circuit with solar input. 7 level inverter made up of IGBT/Diode switch the MATLAB simulation is synchronized with the FPGA sparton to develop the pulse and the same is sent to the hardware model.

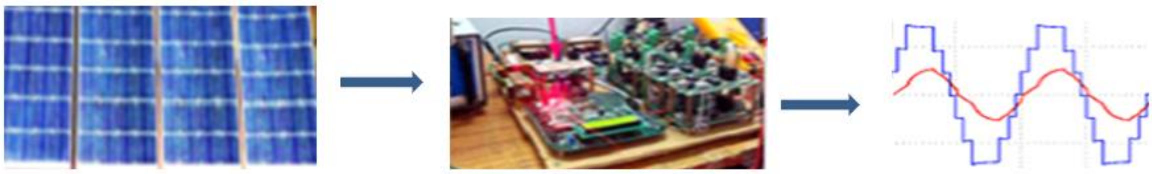


Figure 14. Hardware setup of the proposed model

5. CONCLUSION

In this paper, we experimented and analyzed the hybrid GWO–RNN, LUO converter and a MLI system for the grid connected PV applications to achieve an efficient MPPT tracking system. The reference research papers has been reviewed to know the existing works and to precise our project works. Based on this, we simplified and used hybrid tracking systems in the circuit diagram. We tested and simulated the system using MATLAB simulation tool and the results of voltage source inverter (MLI), LUO converter and the overall system of solar PV arrays. And the results we obtained is very effective and efficient and it also have evidently compared with hardware results.

ACKNOWLEDGEMENTS

The authors would like to share my greetings to my guide and co scholors who had helped me in this work. Thanks to render my thanks to my college which gives me a wide support related to the technical side by giving me a wonderful lab setup for exiciting this work.

REFERENCES

[1] A. Sangwongwanich, Y. Yang, F. Blaabjerg, and D. Sera, "Delta power control strategy for multistring grid-connected PV inverters," *IEEE Transactions on Industry Applications*, vol. 53, no. 4, pp. 3862–3870, Jul. 2017, doi: 10.1109/TIA.2017.2681044.

[2] Y. K. Semero, D. Zheng, and J. Zhang, "A PSO-ANFIS based hybrid approach for short term PV power prediction in microgrids," *Electric Power Components and Systems*, vol. 46, no. 1, pp. 1–9, Jan. 2018, doi: 10.1080/15325008.2018.1433733.

[3] M. J. Z. Zadeh and S. H. Fathi, "A new approach for photovoltaic arrays modeling and maximum power point estimation in real operating conditions," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 12, pp. 9334–9343, Dec. 2017, doi: 10.1109/TIE.2017.2711571.

[4] O. Abedinia, M. S. Naderi, A. Jalili, and A. Mokhtarpour, "A novel hybrid GA-PSO technique for optimal tuning of fuzzy controller to improve multi-machine power system stability," *International Review of Electrical Engineering*, vol. 6, no. 2, pp. 863–873, 2011.

[5] A. G. Al-Gizi, A. Craciunescu, and S. J. Al-Chlaihawi, "The use of ANN to supervise the PV MPPT based on FLC," in *2017 10th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2017*, 2017, pp. 703–708, doi: 10.1109/ATEE.2017.7905128.

[6] L. P. Ling and N. A. Azli, "SVM based hysteresis current controller for a three phase active power filter," in *National Power and Energy Conference, PECon 2004 - Proceedings*, 2004, pp. 132–136, doi: 10.1109/PECON.2004.1461630.

[7] H. Abu-Rub, A. Iqbal, S. M. Ahmed, F. Z. Peng, Y. Li, and G. Baoming, "Quasi-Z-source inverter-based photovoltaic generation system with maximum power tracking control using ANFIS," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 11–20, Jan. 2013, doi: 10.1109/TSTE.2012.2196059.

[8] M. Bagheri, V. Nurmanova, O. Abedinia, and M. Salay Naderi, "Enhancing power quality in microgrids with a new online control strategy for DSTATCOM using reinforcement learning algorithm," *IEEE Access*, vol. 6, pp. 38986–38996, 2018, doi: 10.1109/ACCESS.2018.2852941.

[9] H. Darvish, S. Rahmani, A. Maleki Sadeghi, and M. H. Emami Baghdadi, "The ANFIS-PSO strategy as a novel method to predict interfacial tension of hydrocarbons and brine," *Petroleum Science and Technology*, vol. 36, no. 9–10, pp. 654–659, Mar. 2018, doi: 10.1080/10916466.2018.1442852.

[10] M. Mir, M. Kamyab, M. J. Lariche, A. Bemani, and A. Baghban, "Applying ANFIS-PSO algorithm as a novel accurate approach for prediction of gas density," *Petroleum Science and Technology*, vol. 36, no. 12, pp. 820–826, Mar. 2018, doi: 10.1080/10916466.2018.1446176.

[11] E. A. R. Engku Ariff, O. Dordevic, and M. Jones, "A space vector PWM technique for a three-level symmetrical six-phase drive," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 11, pp. 8396–8405, Nov. 2017, doi: 10.1109/TIE.2017.2703668.

[12] W. Wang, J. Zhang, and M. Cheng, "A dual-level hysteresis current control for one five-leg VSI to control two PMSMs," *IEEE Transactions on Power Electronics*, vol. 32, no. 1, pp. 804–814, Jan. 2017, doi: 10.1109/TPEL.2016.2535294.

[13] A. Lashab, D. Sera, J. M. Guerrero, L. Mathe, and A. Bouzid, "Discrete model-predictive-control-based maximum power point tracking for PV systems: overview and evaluation," *IEEE Transactions on Power Electronics*, vol. 33, no. 8, pp. 7273–7287, Aug. 2018, doi: 10.1109/TPEL.2017.2764321.

[14] N. Priyadarshi, S. Padmanaban, P. Kiran Maroti, and A. Sharma, "An extensive practical investigation of FPSO-based MPPT for grid integrated PV system under variable operating conditions with anti-islanding protection," *IEEE Systems Journal*, vol. 13, no. 2, pp. 1861–1871, Jun. 2019, doi: 10.1109/JSYST.2018.2817584.

[15] N. A. Windarko, A. Tjahjono, D. O. Anggriawan, and M. H. Purnomo, "Maximum power point tracking of photovoltaic system using adaptive modified firefly algorithm," in *Proceedings - 2015 International Electronics Symposium: Emerging Technology in Electronic and Information, IES 2015*, Sep. 2016, pp. 31–35, doi: 10.1109/ELECSYM.2015.7380809.

[16] R. B. A. Koad, A. F. Zobaa, and A. El-Shahat, "A novel MPPT algorithm based on particle swarm optimization for photovoltaic systems," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 468–476, Apr. 2017, doi: 10.1109/TSTE.2016.2606421.

[17] N. Kumar, I. Hussain, B. Singh, and B. K. Panigrahi, "Framework of maximum power extraction from solar PV panel using self predictive perturb and observe algorithm," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 2, pp. 895–903, Apr. 2018, doi: 10.1109/TSTE.2017.2764266.

[18] D. C. Huynh and M. W. Dunnigan, "Development and comparison of an improved incremental conductance algorithm for tracking the MPP of a solar PV panel," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 4, pp. 1421–1429, Oct. 2016, doi: 10.1109/TSTE.2016.2556678.

[19] D. Rekioua and E. Matagne, "Modeling of solar irradiance and cells," in *Optimization of Photovoltaic Power Systems*, Springer London, pp. 31–87, 2012.

[20] A. K. Rathore, J. Holtz, and T. Boller, "Synchronous optimal pulsewidth modulation for low-switching-frequency control of medium-voltage multilevel inverters," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2374–2381, Jul. 2010, doi: 10.1109/TIE.2010.2047824.

[21] A. K. Rathore, J. Holtz, and T. Boller, "Generalized optimal pulsewidth modulation of multilevel inverters for low-switching-frequency control of medium-voltage high-power industrial AC drives," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 10, pp. 4215–4224, Oct. 2013, doi: 10.1109/TIE.2012.2217717.

[22] D. Karthikeyan, V. Krishnasamy, and M. A. J. Sathik, "Development of a switched diode asymmetric multilevel inverter topology," *Journal of Power Electronics*, vol. 18, no. 2, pp. 418–431, 2018, doi: 10.6113/JPE.2018.18.2.418.

[23] T. Brückner, S. Bernet, and H. Güldner, "The active NPC converter and its loss-balancing control," *IEEE Transactions on Industrial Electronics*, vol. 52, no. 3, pp. 855–868, Jun. 2005, doi: 10.1109/TIE.2005.847586.

[24] T. B. Soeiro and J. W. Kolar, “The new high-efficiency hybrid neutral-point-clamped converter,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 5, pp. 1919–1935, May 2013, doi: 10.1109/TIE.2012.2209611.
[25] Z. Du, L. M. Tolbert, J. N. Chiasson, and B. Özpineci, “A cascade multilevel inverter using a single DC source,” in *Conference Proceedings - IEEE Applied Power Electronics Conference and Exposition - APEC*, 2006, vol. 2006, pp. 426–430, doi: 10.1109/apec.2006.1620573.
[26] V. K. Karthikeyan. D , Anindya. C , Surendhirababu.K , Arumbu V.P, “Cloud storage based IoT control automatic street light activation system,” *Solid State Technology*, vol. 63, no. 3, pp. 400–406, 2020.
[27] D. Karthikeyan, V. P. Arumbu, P. Divya, K. Vijayakumar, and K. Mani Rahulan, “Energy conservation at high power consuming holding furnace with modified coil design and electrical circuits,” *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 2, pp. 803–810, Jun. 2021, doi: 10.11591/ijpeds.v12.i2.pp803-810.
[28] D. Karthikeyan *et al.*, “Sophisticated and modernized library running system with OCR algorithm using IoT,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 3, pp. 1680–1691, Dec. 2021, doi: 10.11591/ijeecs.v24.i3.pp1680-1691.

BIOGRAPHIES OF AUTHORS

Arumbu Venkadasamy Prathaban received her B.E. degree from the Department of Electrical and Electronics Engineering from Kalasalingam College of Engineering and Technology, Chennai, India (affiliated with Anna University, Chennai, India), in 2005; and her M.Tech. degree in Power Electronics and Drives from SRMIST (Formerly SRM University), Kattankulathur, India, in 2013. She is now pursuing her Ph.D. at SRMIST. She formerly worked as a lecturer in the EEE department at Thiru Seven Hills Polytechnic, and before that at SA Polytechnic in Chennai, India. Power Electronics and Multilevel Inverters are two of her main research interests. She can be contacted at email: av8168@srmist.edu.in.

Dhandapani Karthikeyan received a B.E. Degree in Electrical and Electronic Engineering from A.I.H.T College in Chennai, India (associated with Anna University in Chennai, India) in 2009, and an M.Tech. He earned his bachelor's degree in Power Electronics and Drives from SRMIST (previously SRM University) in Kattankulathur, India, in 2013, and his Ph.D. in Multilevel Inverters in 2019. He is presently employed as an Assistant Professor in the Department of Electrical Engineering at SRMIST (previously SRM University) in Kattankulathur and Chennai, India. His current research interests include power electronic multilevel inverters, alternating current drives, and direct current drives. He is a member of several professional organisations, including the IEEE, IET, IEI, and ISCA. He can be contacted at email: karthipncl@gmail.com.