LSTM-ANN Controllers based Grid Connected Hybrid PV-Wind-Battery Power Supply System

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Abstract- Electric power generation through hybrid renewable energy sources is a best solution for solution of many problems. In order to achieve the best performance of the model, a multilevel inverter must be incorporated between dc-link and load bus. However, multilevel inverters are suffering with high number of switches. Hence, a closed loop control method of a seven level aligned multilevel inverter is implemented in this paper to improve the power quality. PMSG coupled wind power conversion system, PV and battery operated grid connected system is considered in this paper. The proposed aligned multilevel topology required only half number of switches compared to existing basic topologies. A new SPWM method is implemented in this paper to generate the required pulses to the inverter. As compared with PI controllers, LSTM based ANN controllers are having superior performance during sudden changes in the system. Hence the control of inverter is developed by using LSTM-ANN controller to achieve the better performance. The hardware-in-loop (HIL) is implemented to analyze the response of the system under various operating conditions with the help of OPAL-RT devices.

Keywords Aligned multilevel inverters, grid connected system, PV, PMSG and wind.

Nomenclature:

ANN : Artificial Neural Network
AMI : Aligned Multilevel Inverter
HIL : Hardware – in the – Loop
LSTM : Long Short-Term Memory
MPPT : Maximum Power Point Tracking
NSPWM : New Sinusoidal Pulse Width Modulation
PCC : Point of Common Coupling
P and O : Perturbation and observation
PV : Photovoltaic
PMSG : Permanent Magnet Synchronous Generator
RMS : Root Mean Square
THD : Total Harmonic Distortion

1. Introduction

Electric power with quality supply is required by every customer to operate their loads to fulfill some needs. In this regards, a locally placed standalone and grid connected power supply systems are famous in many places which used to supply power to loads [1-3]. Therefore, renewable energy sources operated grid connected power supply systems are becoming more popular and easy to establish at many places worldwide. In general, maximum loads which are operated in a three phase distribution system are single phase loads. Hence, a proper control algorithm must be required to maintain constant voltage during the operation of unbalance [3-4]. Wind and Solar are two major power sources available for power generation. Hence a hybrid system is considered in this paper for power supply system. Integration of PMSG operated wind and PV can be able to provide reliable power to loads. Unfortunately, both sources are in intermittent

changes in the nature. To overcome this problem, a battery bank is also incorporated into the system.

Required number of batteries is connected in the system through a bidirectional DC to DC circuit [5-6]. The control methodology is developed to regulate the charging & discharging action of the battery. In addition to this, an inverter is required to supply AC power to AC loads from DC source. Therefore, an inverter is in placed between dc-link and load bus through a filter. However, general inverters are converting to DC to square wave type AC which contains higher harmonics. This will be highly affected some sensitive loads. In order to operate loads in safe zone, a multilevel inverter must be considered. Many topologies are available worldwide, but those are suffering with higher number of switches. More number of switches used for constructing multilevel inverter is having many drawbacks including size, compact, efficiency, operation etc. Therefore, a new topology name parallel inverter is implemented in this paper with very few numbers of switches.

A seven level aligned multilevel inverter is considered in between dc-link and filter to convert DC supply into AC power. New SPWM (NSPWM) technique is implemented for generating pulses for switches used in a seven level proposed configuration. The seven level aligned multilevel inverter configurations required only 6 switches per phase.

Various converters are interfaced in the system to achieve the stable dc-link voltage. Boost converters are employees with both PV and wind system to operate as MPPT circuit [7]. In order to reduce some converters, PV system is directly connected to the dc-link and control of bidirectional dc to dc converter can able to work as MPPT device for the PV system. A novel closed loop control of inverter is implemented with the help of long short-term memory (LSTM)-based artificial neural network (ANN) to supply quality power into loads in this paper.

Rest of the paper is prepared under following sections. Configuration of a seven level aligned multilevel inverter along with system description of a grid connected system is presented in Section – II. The control method is implemented in Section – III. By using OPAL-RT devices, and Hardware – in the – Loop (HIL) is established for presenting various results in Section – IV. Section – V compressed with conclusions. Reference list is provided at the end of the paper.

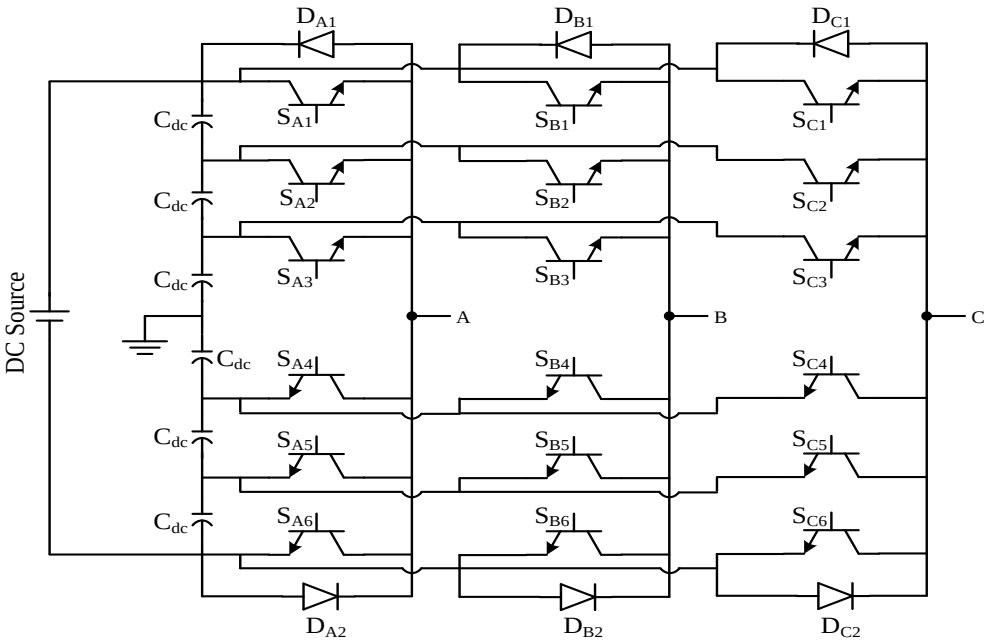


Fig. 1. A seven level of three phase parallel inverter.

2. System Description and Configuration

The proposed configuration of a seven level aligned multilevel inverter is shown in Fig. 1 which constructed by using only 6 number of switches per phase. The main advantage of this configuration is required only (m-1) switches for 'm' level per phase. This proposed seven level aligned multilevel inverter is used in the renewable energy sources supplied isolated system. A model block diagram of the system is shown in Fig. 2. The PV and Wind systems are connected to the same dc-link voltage where battery also incorporated with a bidirectional DC/DC converter. A simple RMS voltage based closed loop control is developed to regulate voltage at load bus. Ratings of PV system and wind system are given in Table. 1 and Table. 2 respectively. Constant torque based MPPT system is incorporated for wind system on a boost converter. All AC loads are operated at point of common coupling (PCC) as shown in Fig. 2. Other parameters of the system are collected from [1-4].

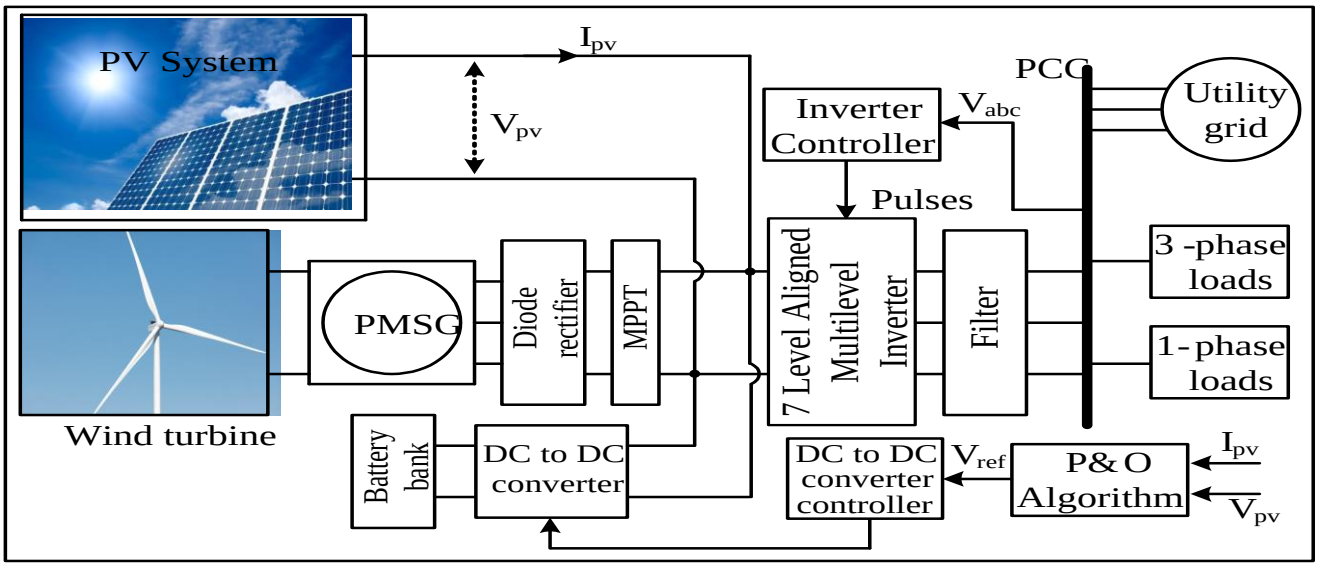


Fig. 2. Hybrid grid connected power supply system.

Table 1. Rating of PV system [8-10]

Parameter	Value
Module Open circuit voltage.	36.9V
Short circuit current.	8.01A
V_{mpp}	30.30V
I_{mpp}	7.10A
Resistance of series.	0.0045Ω
Shunt resistance.	0.9822Ω
Cell diode voltage.	0.5367V
Series connected modules.	22
Irradiance G.*	1000W/m^2
Rated power.	4.73kW

Table 2. Ratings of wind turbine [1, 11]

Parameter	Value
Air density.	1.255Kg/m^3
Blades Area swept.	1.06m^2
Optimum coefficient.	1.678x10e-3Nm/(rad/s)
Wind speed base.	12.0m/s
Pole pairs.	5
Rated speed.	153rad/s
Resistance at Armature.	0.425Ω
Stator inductance.	8.4mH
Flux linkage.	0.433wb
Rated armature current.	12.0A
Maximum torque.	40 N-m
Rated power.	6.4kW

3. Control Strategy

The MPPT algorithm of PV system (i.e., P&O) is integrated with the control of dc to dc bidirectional converter. Hence no need of an extra circuit for MPPT of the PV system. The hybrid proposed control is depicted in Fig. 3. The control of dc to dc bidirectional converter is able to regulate the voltage at dc-link. The inverter control can easily inject the excess power into utility grid once stabilized the voltage at dc-link. Proposed control block of inverter is shown in Fig. 4 which is a closed loop designed for maintaining a proper voltage at load bus. The individual phase RMS voltages are compared with their reference signal and generated modulation index by using PI controller. A NSPWM method is also implemented which is based on comparing carrier waves to their reference wave as depicted in Fig. 5. Where signals AT1, AT2 & AT3 are generated pulses by comparing carrier and reference sinusoidal waveforms. Conventional SPWM technique is available to control the inverter. Every switch will get pulse when it's ON during the process of SPWM technique. However, in the proposed method, no need of have generated switching pulse continuously. Hence NSPWM is developed with the help of gates. The normal ON time of each device is 1/(N-1) times the total time where total number of switcher are 'N'. At the same time remaining all other switches in the same phase are in OFF state.

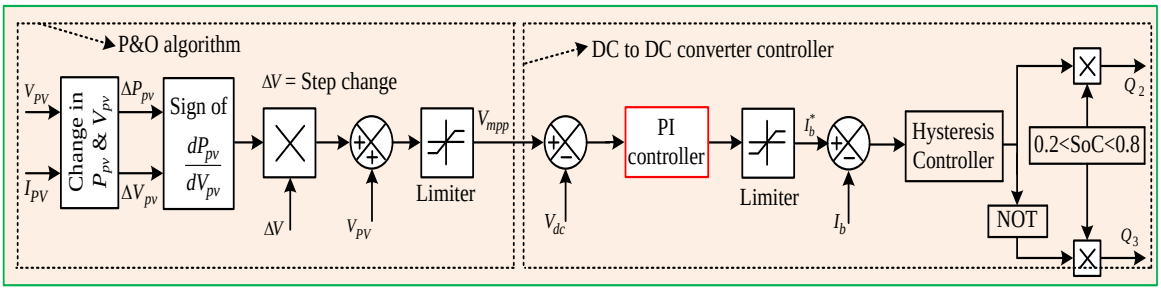


Fig. 3. MPPT of PV system associated to control of dc to dc bidirectional converter.

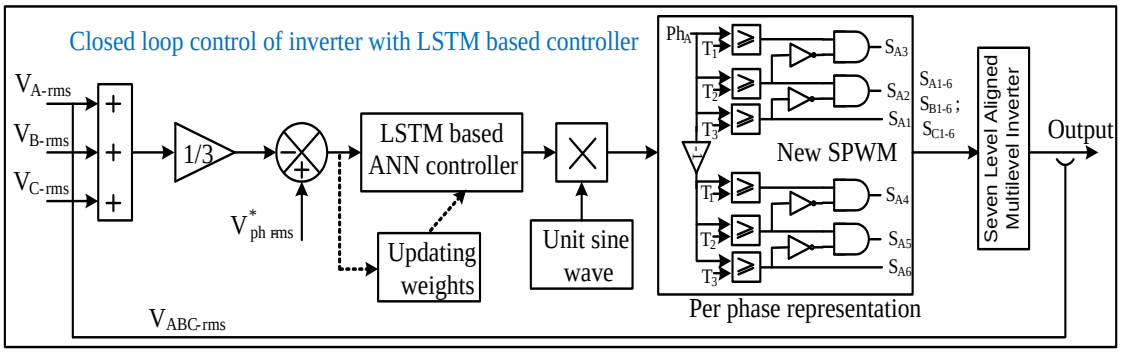


Fig. 4. Simple closed loop control of grid connected system (inverter).

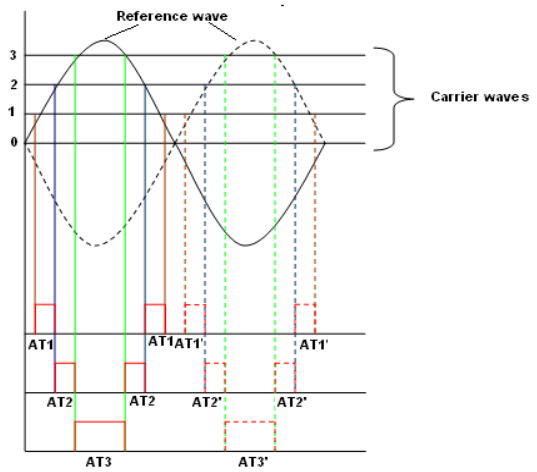


Fig. 5. New SPWM technique.

In this paper, an ANN-based long short-term memory (LSTM) algorithm is implemented to handle the data of the grid connected hybrid system. The LSTM algorithm, which is derived from references [18-20], is employed to enhance the capabilities of the ANN controller. Additionally, a deep learning algorithm is utilized to update the weights of the ANN controller, allowing for adaptive learning and improved performance. To nullify the noise signal in the grid connected model, memory cells are incorporated in the design of the ANN-based controller unit, as depicted in Fig. 6. The internal structure of the LSTM network is established using fundamental equations, and the corresponding layout is illustrated in Fig. 7. Further, a machine learning algorithm is developed to facilitate the updating of neuron weights in the system according to specific requirements. Additionally, an unknown noise signal (ns) is considered in the analysis, as there may be interfacing magnetic signals in the system resulting from high voltage and other components. These signals need to be suppressed, and thus, the opposite polarity is taken into account for each element in the LSTM block.

$$a_t = \sigma(b_a + h_{t-1} \times w_{ah} + X_t \times w_{ax} \mp n_{sa}) \quad (1)$$

$$f_t = \sigma(b_f + h_{t-1} \times w_{fh} + X_t \times w_{fx} \mp n_{sf}) \quad (2)$$

$$O_t = \sigma(b_o + h_{t-1} \times w_{oh} + X_t \times w_{ox} \mp n_{so}) \quad (3)$$

$$\hat{C}_t = \tanh(b_c + h_{t-1} \times w_{ch} + X_t \times w_{cx} \mp n_{sc}) \quad (4)$$

$$s_t = f_t \otimes s_{t-1} + \hat{C}_t \times a_t \quad (5)$$

$$h_t = \tanh(s_t) \otimes O_t \quad (6)$$

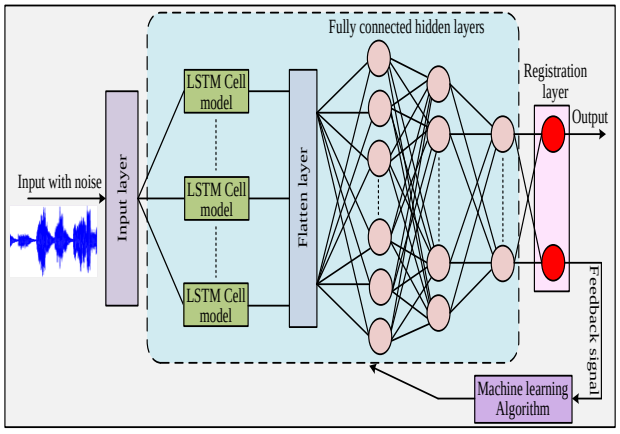


Fig. 6. LSTM based ANN controller.

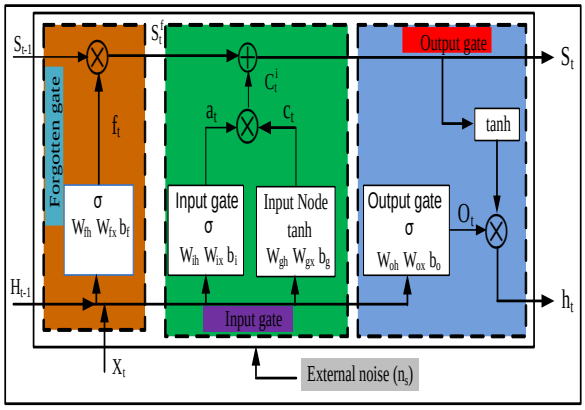


Fig. 7. Model of a single LSTM cell.

The gains of the PI controllers are listed in Table 3.

Table. 3. Gains of controllers

S.No	Parameters	values
PI for control of Battery converter.		
1	Kp.	2.787
2	Ki.	68.18
Hysteresis band = 10%.		

4. Results and Discussion

In this work, the system's performance is improved under diverse scenarios using real-time simulators (RTS) [12-14]. The RTS modules such as OPAL-RT devices are used to obtain HIL setup in the laboratory. Two OPAL-RT modules are used to establish HIL for making real time experience on testing of proposed complex controllers. The plant which consists of grid connected system is dumped in OPAL-RT module 1 (i.e., OPAL RT-1). All the control methods are dumped in OPAL-RT module 2 (i.e., OPAL RT-2). The analog signals from the plant are converted to digital for making input to the controller unit (i.e., OPAL RT-2) through data cards. The controller module can perform as per designed controllers and generates respective switching pulses for converters used in the plant. The digital pulses will be converted to analog signals to make input signals for plant through external data cards. The required results are carried out by using a laptop instead of an oscilloscope for presenting with better visualization. The basic HIL setup with two OPAL-RT devices is depicted in Fig. 8. Various parameters used in modeling of the proposed method are considered from [15-27]. Te HIL model of the proposed method is depicted in Fig. 9 along with flow of various signals.

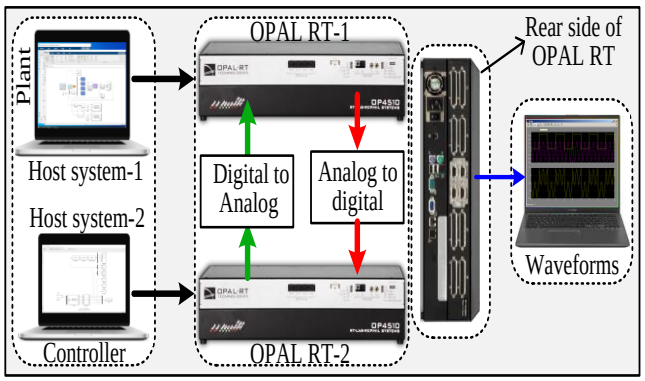


Fig. 8. HIL setup with two OPAL-RT modules.

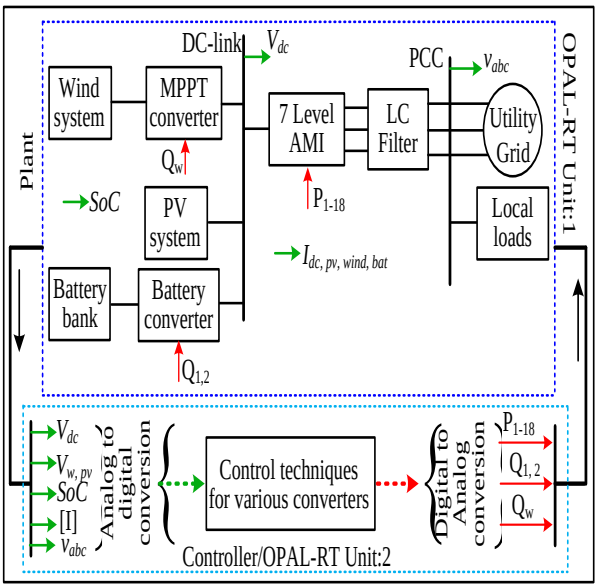


Fig. 9. HIL representation of proposed method.

Case 1: DC-link voltage during applying load:

There will be changes in voltage at dc-link according to changes in the load at PCC. Considered 100% change in load suddenly applied at t=3.0sec and removed at t=4.0sec. Corresponding waveform of voltage at dc-link is presented in Fig. 10. Small voltage dip is occurred when connected load and spike happened when released the load. Instantaneous line to line voltage at t=2.0sec are also presented in Fig. 11 for more clarity on voltage quality.

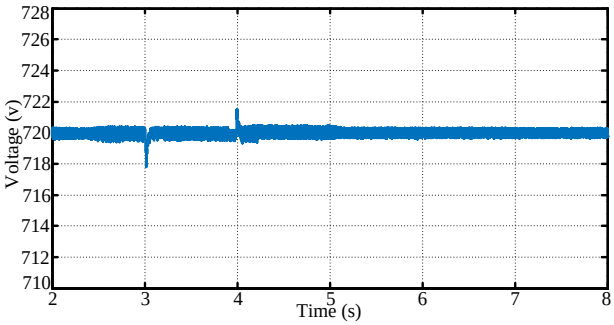


Fig. 10. Voltage at dc-link during change in load at PCC.

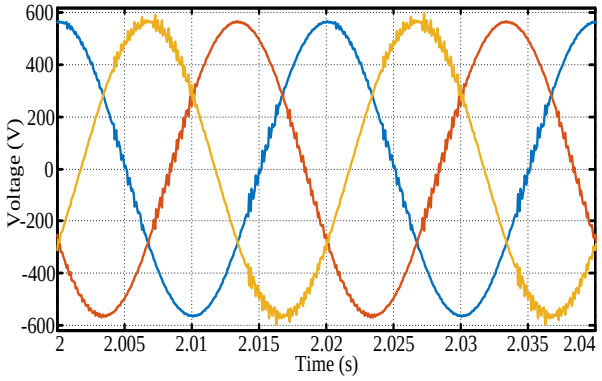


Fig. 11. Line to Line voltages at PCC.

Case 2: For unbalanced load

The system is now tested under the operation of unbalanced load. The three phased unbalanced load which depicted in Fig. 12 is connected at load bus. The RMS voltage at load bus is maintaining constant during this operation as evident as shown in Fig. 13.

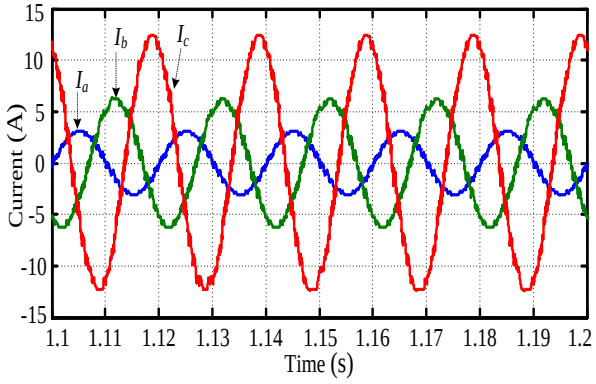


Fig. 12. Load current.

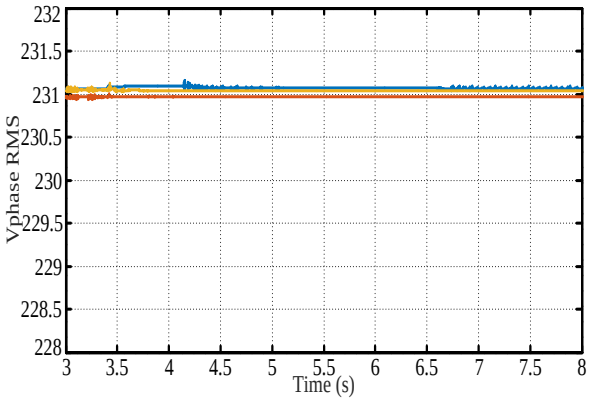


Fig. 13. RMS voltage.

Case-3: Intermittency in wind speed, solar irradiance, and variations at load bus:

In practical scenario, loads at load bus, wind speed and solar irradiances are always varies randomly as shown in Fig. 14. During this condition, the controllers should maintain constant voltages at both dc-link as well as load bus as depicted in Fig. 15.

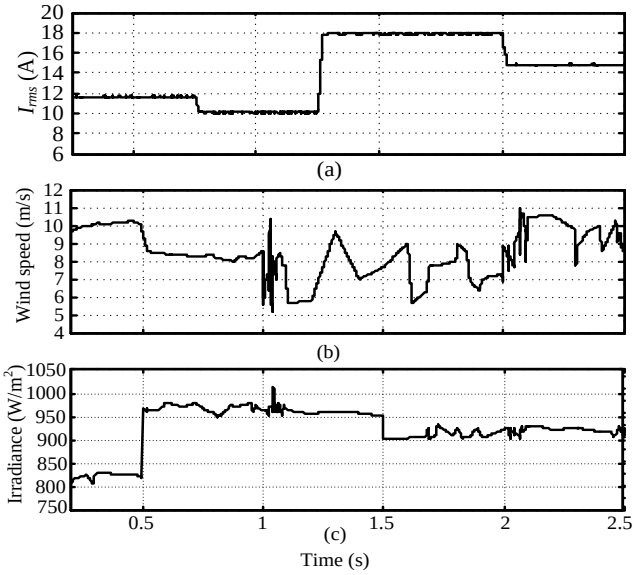


Fig. 14. Variations in (a) Load, (b) Wind velocity, (c) irradiance of solar.

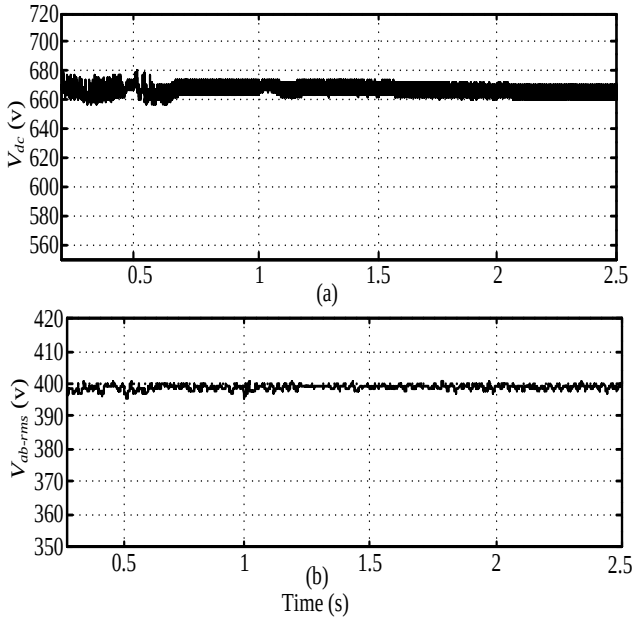


Fig. 15. (a) Dc-link voltage, (b) PCC voltage.

The corresponding powers of PV, wind and grid is depicted in Fig. 16 for changes mentioned in Fig. 14. Instantaneous voltage profile is also shown in Fig. 17. Corresponding current of phase A is shown in Fig. 18. The THD of line to line voltage at PCC is depicted in Fig. 19 with the help of FFT analysis.

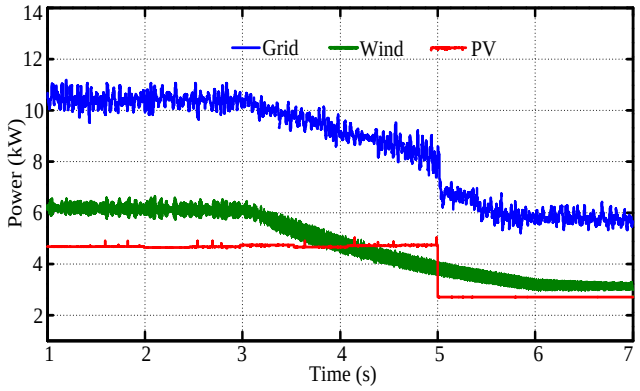


Fig. 16. Various Powers

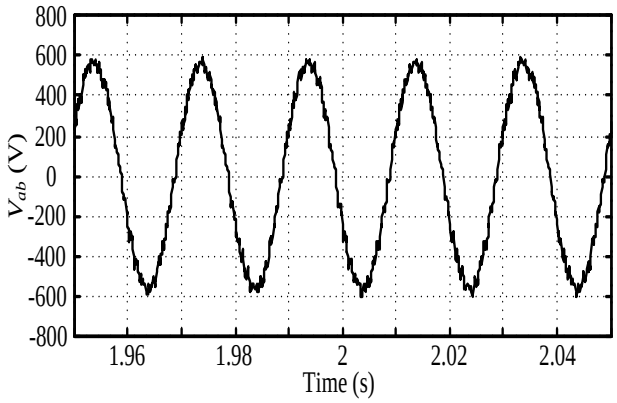


Fig. 17. Instantaneous line voltages at PCC.

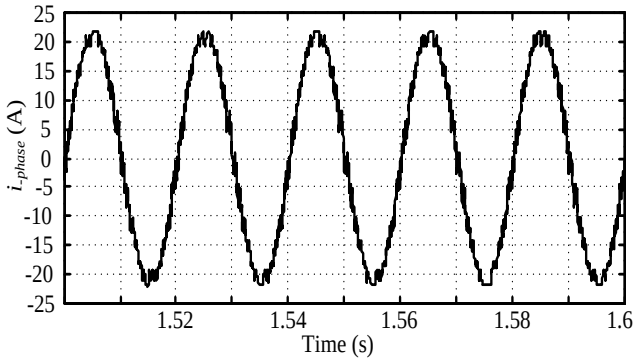


Fig. 18. Instantaneous phase currents.

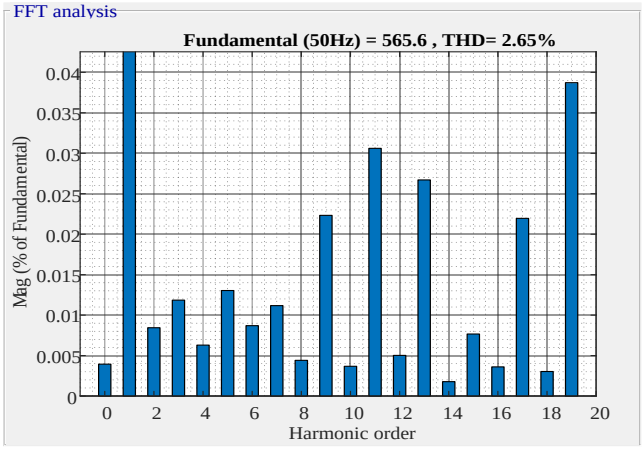


Fig. 19. THD of line to line voltage at PCC.

5. Conclusion

New topology of multilevel inverter namely as aligned multilevel inverter is used in grid connected hybrid system to improve the quality of power. A seven level aligned multilevel inverter is used in this paper. Hybrid wind, PV based grid connected system is developed in this paper and a simple control method is developed to maintain power quality at PCC. The control method is developed with the help of LSTM-ANN controller to obtain precious responses under various operating conditions. HIL based results are incorporated in this paper under various case studies. The proposed method is giving satisfactory performance under changes of irradiance, load and wind speed even under unbalanced load operations.

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References

[1] J. K. Singh, S. Prakash, K. Al Jaafari, O. Al Zaabi, K. Al Hosani, R. K. Behera, and U. R. Mudul, "Active disturbance rejection control of photovoltaic three-phase grid following inverters under uncertainty and grid voltage variations", in IEEE Transactions on Power Delivery, vol. 38, no. 5, pp. 3155-3168, Oct. 2023, https://doi.org/10.1109/TPWRD.2023.3266898.

[2] J. K. Singh, K. A. Jaafari, R. K. Behera, K. A. Hosani and U. R. Muduli, "Faster convergence controller with distorted grid conditions for photovoltaic grid following inverter system", in IEEE Access, vol. 10, pp. 29834-29845,2022, https://doi.org/10.1109/ACCESS.2022.3159476.

[3] M. Sharifzadeh, H. Vahedi, R. Portillo, L. G. Franquelo and K. Al-Haddad, "Selective harmonic mitigation based self-elimination of triplen harmonics for single-phase five-level inverters", in IEEE Transactions on Power Electronics, vol. 34, no. 1, pp. 86-96, Jan. 2019, https://doi.org/10.1109/TPEL.2018.2812186.

[4] H. Vahedi, P. A. Labbé and K. Al-Haddad, "Sensor-Less five-level packed u-cell (PUC5) inverter operating in stand-alone and grid-connected modes", in IEEE Transactions on Industrial Informatics, vol. 12, no. 1, pp. 361-370, Feb. 2016, doi: 10.1109/TII.2015.2491260.

[5] S. G. Malla, J. M. R. Malla, P. Malla, S. Ramasamy, S.K. Doniparthi, M. K. Sahu, P. K. Subudhi, H. Awad. "Coordinated power management and control of renewable energy sources based smart grid" International Journal of Emerging Electric Power Systems, vol. 23, no. 2, 2022, pp. 261-276. https://doi.org/10.1515/ijeeps-2021-0113.

[6] A. Dash, U. P. Bagarty, P. K. Hota, R. K. Behera, U. R. Muduli, and Khalifa Al Hosani, "DC offset compensation for three-phase grid-tied SPV-DSTATCOM under partial shading condition with improved PR control", IEEE Access vol.9,2021, https://doi.org/ 101109/ACESS.2021.3115122.

[7] K. B. Prakash, "PV-Battery based standalone power supply system for rural applications", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 8, Issue. 12, pp. 9-13, Dec. 2022, https://doi.org/10.1109/UPCON.2018.8597005.

[8] C. Pradhan, M. K. Senapati, S. G. Malla, P. K. Nayak and T. Gjengedal, "Coordinated power management and control of standalone PV-hybrid system with modified IWO-Based MPPT", in IEEE Systems Journal, vol. 15, no. 3, pp. 3585-3596, Sept. 2021, https://doi.org/10.1109/JSYST.2020.3020275.

[9] L. Schwager, A. Tüysüz, C. Zwyssig and J. W. Kolar, "Modeling and comparison of machine and converter losses for PWM and PAM in high-speed drives", in IEEE Transactions on Industry Applications, vol. 50, no. 2, pp. 995-1006, March-April 2014, https://doi.org/ 10.1109/TIA.2013.2272711.

[10] M. Landína, R. C. Roweb, P. Yorkb, "Advantages of neurofuzzy logic against conventional experimental design and statistical analysis in studying and developing direct compression formulations", European Journal of Pharmaceutical Sciences, Vol. 38, pp. 325–331, 2009, https://doi.org/10.1016/j.ejps.2009.08.004.

[11] U. R. Muduli, K. A. Jaafari, K. A. Hosani, R. K. Behera, R. R. Khusnutdinov and A. R. Safin, "Cell balancing of li-ion battery pack with adaptive generalised extended state observers for electric vehicle applications", 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 2021, pp. 143-147, https://doi.org/ 10.1109/ECCE47101.2021.9595601.

[12] F. M. Ibanez, "Analyzing the need for a balancing system in supercapacitor energy storage systems", in IEEE Transactions on Power Electronics, vol. 33, no. 3, pp. 2162-2171, March 2018, https://doi.org/: 10.1109/TPEL.2017.2697406.

[13] M. Nagaraju, M. K. Kumar, "Seven-level symmetrical series/parallel multilevel inverter with PWM technique using digital logic" International Journal of Electrical and Computer Engineering Systems, Vol. 12, no. 3, pp. 123-130, Sep 2021,https://doi.org/10.32985/ijeces.12.3.

[14] E. H. Dursun and A. A. Kulaksiz, "MPPT control of PMSG based small-scale wind energy conversion system connected to dc-bus", International Journal of Emerging Electric Power Systems, vol. 21, no. 2, 2020, pp. 20190188. https://doi.org/10.1515/ijeeps-2019-0188.

[15] B. M. Prasad and P. K. Ray, "Reactive power and harmonic compensation in a grid-connected photovoltaic system using fuzzy logic controller" International Journal of Emerging Electric Power Systems, vol. 22, no. 2, 2021, pp. 161-175. https://doi.org/10.1515/ijeeps-2020-0204.

[16] M A. Shamshuddin, T. S. Babu, T. Dragicevic, M. Miyatake, N. Rajasekar, "Priority-based energy management technique for integration of solar PV, battery, and fuel cell systems in an autonomous DC microgrid", Electric Power Components and Systems, 2018 45, no. 17, pp. 1881-1891, https://doi.org/10.1080/15325008.2017.1378949.

[17] R. Hegazy, T. S. Babu, M. Al-Dhaifallah, and H. A. Ziedan", A robust parameter estimation approach based on stochastic fractal search optimization algorithm applied to solar PV parameters", Energy Reports, vol. 7, Nov 2021, pp.620-640, https://doi.org/10.1016/j.egyr.2021.01.024.

[18] E. Balouji, I. Y. H Gu, M. H. J. Bollen, A. Bagheri, M. Nazari, "A LSTM-based deep learning method with application to voltage dip classification", 2018 18th International Conference on Harmonics and Quality of Power (ICHQP), Ljubljana, Slovenia, 2018, pp. 1-5, https://doi.org/10.1109/ICHQP.2018.8378893.

[19] A. Dash, D. P. Bagarty, P. K. Hota, U. R. Muduli, K. A. Hosani and R. K. Behera, "Performance evaluation of three-phase grid-tied SPV-DSTATCOM with DC-offset compensation under dynamic load condition", in *IEEE Access*, vol. 9, pp. 161395-161406,2021, https://doi.org/10.1109/ACCESS.2021.3132549.

[20] V. Narayanan, S. Kewat and B. Singh, "Solar PV-BES based microgrid system with multifunctional VSC", IEEE Transactions on Industry Applications, Vol. 56, no. 3, pp. 2957-2967, May-June 2020, https://doi.org/ 10.1109/TIA.2020.2979151.

[21] J. K. Singh, K. A. Jaafari, R. K. Behera, K. A. Hosani and U. R. Muduli, "faster convergence controller with distorted grid conditions for photovoltaic grid following inverter system", in IEEE Access, vol. 10, pp. 29834-29845, 2022, https://doi.org/ 10.1109/ACCESS.2022.3159476.

[22] R. K. Meena, D. V. Bhaskar, O. Al Zaabi, M. Panda, P. Kumar and U. R. Muduli, "Modeling of two-stage photovoltaic inverter with grid connected and islanding operation", 2023 IEEE IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT), Male, Maldives, 2023, pp.1-6 https://doi.org/10.1109/GlobConHT56829.2023.10087517.

[23] C. Serir, D. Rekioua, S. Bensmail, A. Belkaid, K. Tadjine and S. Hadji., "Electrification of a load by a hybrid photovoltaic-wind system with battery storage", 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2022, pp. 571-575, doi: 10.1109/ICRERA55966.2022.9922812.

[24] F. Selim, T. F. Megahed, M. Aly, M. Shoyama and S. M. Abdelkader, "model predictive control based

improved techno-economic control strategy for photovoltaic-battery microgrids", 2022 11th International Conference on Renewable Energy Research and Application (ICRERA*)*, Istanbul, Turkey, 2022, pp. 230-235, doi: 10.1109/ICRERA55966.2022.9922814.

[25] S. Goud, T. V. S. Kalyani, K. V. G. Rao, G. S. F. Selim, "Amalgamation of Smart Grid with Renewable Energy Sources", International Journal of Smart Grid, ijSmart Grid, Istanbul, Turkey, 2023,vol.7, no.2, june 2023, doi: https://doi.org/10.20508/ijsmartgrid.v7i2.

[26] J. Arkhangelski, M. Abdou-Tankari and G. Lefebvre, "Efficient abnormal building consumption detection by deep learning LSTM IOT data classification", 2022 11th International Conference on Renewable Energy Research and Application (ICRERA*)*, Istanbul, Turkey, 2022, pp. 125-129, doi: 10.1109/ICRERA55966.2022.9922844.

[27] R. Citroni and P. Livreri, "A novel shape of bowtie antenna arranged in a linear array for energy harvesting in MID-IR band", 2023 12th International Conference on Renewable Energy Research and Applications (ICRERA), Oshawa, ON, Canada, 2023, pp. 248-253, doi: 10.1109/ICRERA59003.2023.10269377.