Journal of Nuclear Energy Science & Power Generation Technology

Research Article

A SCITECHNOL JOURNAL

Power Quality Issues in Autonomous Solar Photovoltaic Utility Microgrid Employing a STATCOM Based Intelligent Controller

Hemavathi S[1,2]*, Archana Nanoty[3], MK Singh[4], Atul Katiyar[5], RP Manohar[6] and Shweta Chourasia[7]

Abstract

Microgrid has emerged as an efficient autonomous decentralized utility grid to reduce the dependency on the regular electric grid. It also benefits in the reduction of unwanted transient and harmonics and results in overall power quality improvement. The study is essentially focused on the Solar PV unit because of its increasing importance and promising outcome despite several inferiorities. It has been observed that a reactive power divergence has created a significant power quality issue in the solar PV-based micro grid system, which in turn results in significant voltage fluctuation and deterioration in overall power quality. This fluctuation has a considerable impact on both steady-state, transient stability and sometimes responsible for the inadequate performance of the solar PV unit. Hence, this work is mainly dedicated to compensate for the reactive power and to overcome the problems of maintaining a constant voltage profile of a solar photovoltaic-based standalone or hybrid microgrid system. Therefore, this study employs a fuzzy controller and a Static Synchronous Compensator (STATCOM); the obtained result or outcome reveals that this proposed novel, cutting-edge system successfully maintains stability and improves power quality in utility PV-microgrids.

Keywords: STATCOM; FLC; Solar PV; Grid

Introduction

As per the world energy outlook report 2020, global electricity demand grows at 2.1% per year to 2040. The incorporation DERs in the energy sector can only meet this dramatic exponential growth demand. The scarcity of fossil fuel has led to the development of a new energy infrastructure called "smart grid." Thus smart grid design is based on green energy technologies such as PV, wind, biomass, hydro, etc. While implementing this as an alternative energy generation wills benefits in lower transmission losses and improved reliability. Instead of using an individual energy generation, the combination of two or more systems will yield better reliable power. As wind and solar are the more prominent sources, this work formulated a hybrid system using wind and solar. However, the output of both the system depends upon the environmental condition. So, energy backup should be implemented to increase the security level of energy available. Hence, battery/fuel cell can be employed as a storage device [1-5]. Thus, the designed microgrid can be operated in either grid-connected/islanded mode. Apart from this pollution-free environment, the microgrid can create power quality problems due to its random output nature. In a standalone system, when the load is changed, the system's voltage profile gets affected due to power variations. If non-linear loads are introduced, current harmonics are injected into the system. Thus, these power quality issues can be eliminated by introducing a filter combination or by FACTS devices. Conventional LC filter technique utilized for power quality issue results in resonance with the system's impedance [6]. Hence, STATCOM can be incorporated to mitigate power quality issues in MG. It can either absorb/inject reactive power into the network. This regulates power flow and improves power quality aspects of the system. Simultaneously, it will remove the stress imposed by wind energy generators also [7]. In order to regulate the operation of STATCOM, controllers are implemented. As the PI controller exhibits a wide range of stability margins, they are not suitable for non-linear variations of microgrid [8]. Various controllers were for the smooth operation of STATCOM. Icosφ controller was introduced to reduce. Power quality problems in a hybrid power system connected [9-10] to the grid [11]. Fuzzy and PI controller was introduced for STATCOM, and their performances were studied over PV-Wind-Diesel- BESS based hybrid energy system [12]. The Battery Energy Source (BESS) in conjunction with a static compensator was proposed Das et al. [13] to mitigate power quality-related problems [14]. The performance analysis of a hybrid wind-diesel system with FPID and ANFIS-PID controller-based STATCOM was investigated [15]. However, no standard method is available for rule base formation. Hence, the membership functions have to be tuned properly to minimize the error. Hence, to disregard the limitations of conventional and AI controllers, an AI controller called FIS controller is proposed in this work. FIS controllers are easy to implement [16-21]. Thus, in this work, a hybrid RES which comprises PV and wind system along with battery backup, is modeled. Here, the reactive power compensation is carried using fuzzy controlled STATCOM.

Solar PV System

System description

The equivalent circuit PV cell Figure 1 is made of semiconductor materials that convert incident solar light energy into electrical energy.

The current/voltage characteristic of PV cell can be expressed as

$$I - I_L - I_0 \exp f(l)\left(\frac{(V + IR_s)}{nV_T} - 1\right) - \left(\frac{(V + IR_s)}{R_{Sh}}\right)$$

Where,

I and V current and voltage of solar panel.

IL=NPIL cell,

NP-Number of parallel cells.

***Corresponding author:** Hemavathi, Assistant Professor, Academy of Scientific and Innovative Research, Ghaziabad 201 002, Uttar Pradesh, India, Email id: hemavathi@cecri.res.in

Received date: September 06, 2021 **Accepted date:** September 21, 2021 **Published date:** September 28, 2021

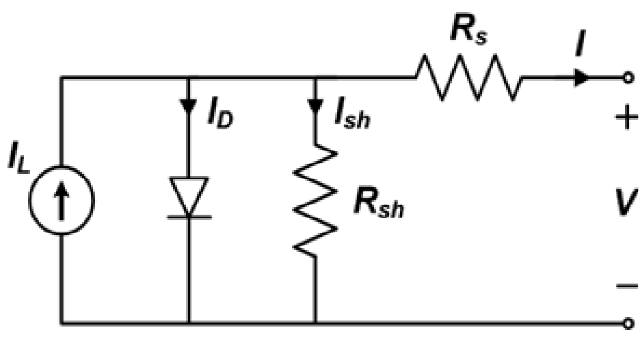

Figure 1: Simplified solar cell model.

Figure 2; depicts the IV/PV characteristics of the PV array utilized in this work.

It is found that when at the lower irradiance value, a slight change in the maximum output voltage is observed, whereas output current changes in drastic nature. Hence, there will be a drop in MPP.

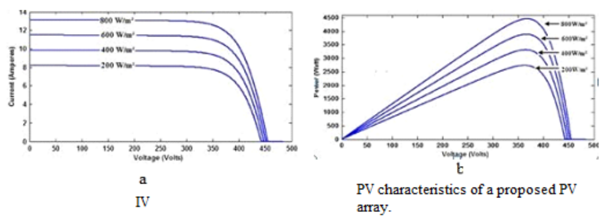

Figure 2: (a) IV and (b) PV characteristics of a proposed PV array.

Power conditioning unit arrangement

The power-conditioning scheme comprises a boost converter with MPPT, a 3FVSI, and an LC filter. Thus, the DC voltage acquired from the PV array is fed into the boost converter. Thus, to obtain the maximum power from the system, the P and O technique is employed. Figure 3 represents the flowchart of P and O topology. The boost converter implemented in this work is shown in Figure 4.

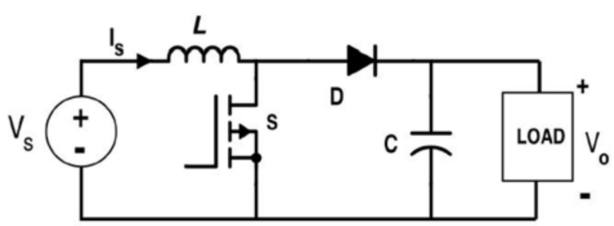

Figure 3: A typical boost converter.

Its operation is as follows: During (0<t ≤ ton):

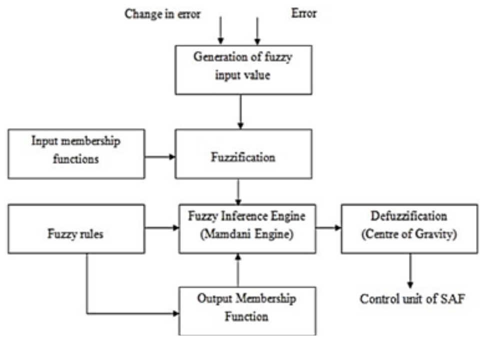

Figure 4: Flowchart representation of FLC.

Switch remains ON and the voltage across L is Vi.

During (ton<t ≤ T): Switch remains OFF and the voltage across L becomes Vi-Vo

The basic idea is to convert the kinetic energy available in the wind into mechanical energy, which rotates the turbine of an electrical generator to produce electrical power. Bernoulli's equation gives us the power available from a wind turbine.

$Pw=1/2\rho AV3$ (2)

$P=1/2CP\rho AV3$ (3)

Where ρ: air density, V: wind density, A: area swept by rotor respectively. However, practically power extracted from a wind turbine generator is the fraction of power Pw. Generator's rotor speed and pitch angle are determining factors for the amount of power extracted (PT). Where CP is called power coefficients whose value normally ranges around 0.593, this is generally referred to as Betz limit. The value of Cp can be controlled using two factors such as β and tip TSR. Finally, the output of the wind and PV systems is integrated and fed to VSI.

STATCOM

STATCOM is a compensating device that can be implemented to control the flow of reactive power in a network and thereby enhance a network's stability. The function of a capacitor in a STATCOM circuit is only to maintain dc voltage at a constant level to aid inverter operation. The capacitor does not produce any reactive power. The dc capacitor voltage can be controlled by having control over the phase angle difference between voltage source converter and line voltage. If the bus angle is advance beyond the phase angle (α), the static compensator increases the injected voltage; reactive power thus flows into the bus. Hence, in order to provide continuous voltage regulation in the microgrid, STATCOM should be controlled using the controller.

Design of fuzzy controller for STATCOM

The flow chart representation of the proposed Fuzzy logic controller is established in Figure 4.\

The FLC utilized in this topology is characterized with

- Seven triangular MF for all inputs and outputs.
- continuous UoD
- Implications are carried using Mamdani's min operator.
- Centroid method is adopted for Defuzzification.

Figure 5 (a-d) depicts MF adopted for both input and output.

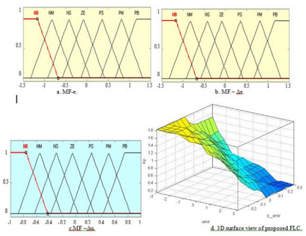

Figure 5: Depicts MF adopted for both input and output (a)MF-e, (b) MF-∆e, (c)MF-∆u, (d)3D surface view of proposed FLC

Results and Discussion

Thus, the performance evaluation of the proposed topology in the MATLAB platform has been discussed in Figure 6

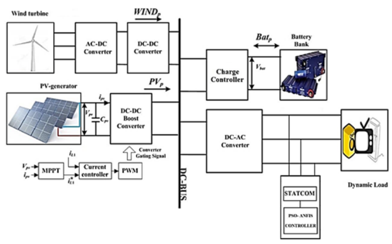

Figure 6: Topology of proposed methodology.

The proposed method's effectiveness is verified under different parameter analyses.

Improvement in voltage stability

The operation of microgrid without STATCOM s reflected in Figure 7.

Thus, it is found that the voltage across the bus varies with time and results in fluctuation, which is about±10%.

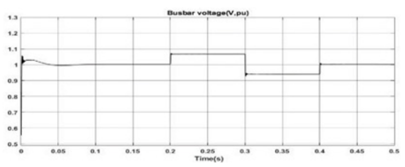

Figure 7: Bus bar voltage profile without STATCOM.

However, when the STATCOM is inserted, the voltage remains constant, as shown in Figure 8, and there is no fluctuation in voltage. Hence, STATCOM with the proposed controller exhibits lower overshoot and minimized voltage fluctuation.

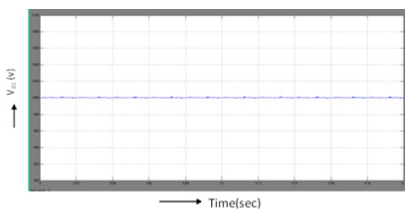

Figure 8: Bus bar voltage profile with STATCOM.

THD calculation and FFT analysis

Figure 9 describes the current and voltage waveforms of the system before STATCO Minjection.

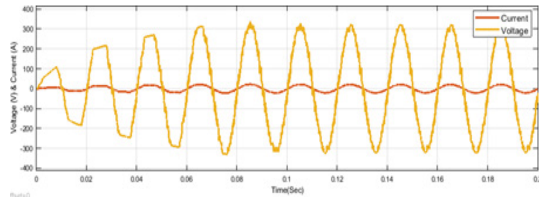

Figure 9: Voltage/current waveform of the system (without STATCOM).

And depicts the current and voltage waveforms of the system without STATCOM. The figure clearly exhibits that there will be more non-linearity in voltage and current waveforms.

Figure 10 depicts the current and voltage waveforms of FL-controlled STATCOM. From that figure, it can be clearly understood that the

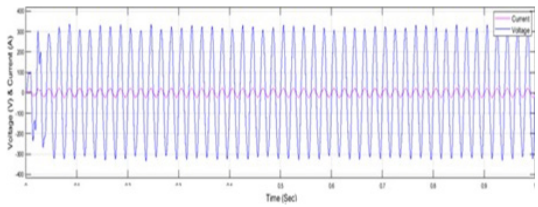

Figure 10: Voltage/current waveform of the system (With STATCOM).

static compensator removes the non-linearity to a great extent. Figure 11 and Figure 12 represent the Total Harmonic Distortion (THD) of the system obtained at the load terminal.

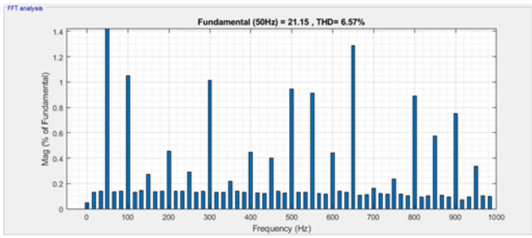

Figure 11: FFT analysis without STATCOM.

From the figures, the Total Harmonic Distortion (THD) considering the maximum frequency as 500 Hz is found out to be 6.50% before compensation. After compensation, it was about 1.20% for the load voltage, i.e., well within the IEEE-519 prescribed limits.

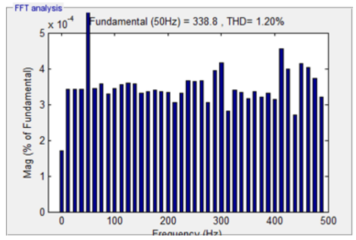

Figure 12: FFT analysis with proposed controller.

Battery performance

Here the Battery complements the part of the total power when the RES failed to supply the demand. Figure 13 portrays the SOC and output voltage of the Battery.

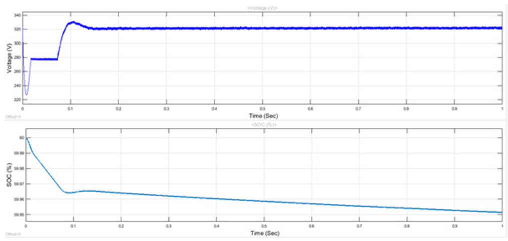

Figure 13: Output voltage/SOC of battery.

The power delivered by the proposed battery is depicted in Figure 14.

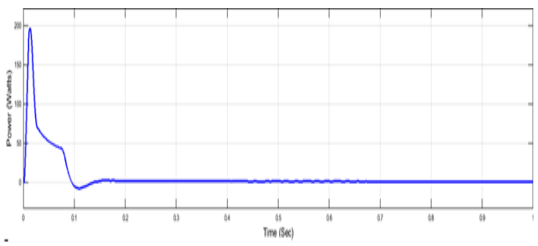

Figure 14: Battery Power.

Conclusion

By understanding the relevance of solar tied microgrids in the current circumstances, authors have been actively motivated to explore and investigate necessary findings and specific outcomes of the proposed scheme in the MATLAB environment. This work principally focused on the PQ issues in Solar PV based standalone or hybrid microgrid; in this work, the formulated MG comprises both PV and wind sources to supply power to the end-user. STATCOM is tailored to mitigate the power quality issues present in the MG. FLC is implemented to control the STATCOM"s dc-link voltage at a constant level. With the help of this FLC-based STATCOM, the proposed work mitigates the harmonics present in the system along with reactive power compensation.

References

1. Wang Q, Wang B, Xu W, Xu J (2018) Research on STATCOM for reactive power flow control and voltage stability in microgrid. In 13th IEEE Conference on Industrial Electronics and Applications (ICIEA). pp: 2474-2479.
2. Mohanty KB, Pati S (2016) Voltage profile improvement of micro-grids using SMC based STATCOM. In Annual IEEE Sys Con pp: 1-8.
3. Suja KR, Raglend IJ (2012) Power quality improvement in grid connected wind energy system using STATCOM. In 2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET). pp; 259-266.
4. Chavan PM, Chavan GP (2017) Interfacing of hybrid power system to grid using statcom and power quality improvement. In 2017 International Conference on Information, Communication, Instrumentation and Control (ICICIC). pp: 1-5.
5. Mosobi RW, Chichi T, Gao S (2015) Power quality analysis of hybrid renewable energy system. Cogent Engineering 2: 1005000.
6. Mohod SW, Aware MV (2010) A STATCOM-control scheme for grid connected wind energy system for power quality improvement. IEEE Systems Journal 4: 346- 352.
7. Suvire GO, Mercado PE (2009) Improvement of power quality in wind energy applications using a DSTATCOM coupled with a flywheel energy storage system. In Brazilian Power Electronics Conference pp: 58-64.
8. Anulal AM, Mohan A, Lathika BS (2015) Reactive power compensation of wind-diesel hybrid system using STATCOM with Fuzzy tuned and ANFIS. International Conference on Control Communication and Computing India (ICCC) pp: 325-330.
9. Das TK, Banik A, Chattopadhyay S, Das A (2019) Sub-harmonics based string fault assessment in solar PV arrays. In: Chattopadhyay S, Roy T, Sengupta S, Berger-Vachon C (eds) Modelling and simulation in science, technology and engineering mathematics MS-17 2017. Adv Intell Sys. 749: 293-301.
10. Das TK, Banik A, Chattopadhyay S, Das A (2019) FFT based classification of solar photo voltaic microgrid system, Second International Conference on Advanced Computational and Communication Paradigms (ICACCP) pp: 1-5.
11. Banik A, Sengupta A (2021) Scope, Challenges, Opportunities and future goal assessment of floating solar park, Innovations in Energy Management and Renewable Resources pp: 1-5.
12. Banik A, Shrivastava A, Manohar Potdar R, Mukesh S (2021) Design, Modelling, and Analysis of novel solar PV system using MATLAB, MaterialsToday: Proceedings.
13. Das TK, Banik A, Chattopadhyay S, Das A (2021) Energy-efficient cooling scheme of power transformer: An innovative approach using solar and waste heat energy technology. In: Ghosh SK, Ghosh K, Das S, Dan PK, Kundu A (2020) Advances in thermal engineering, Manufacturing, and Production Management. ICTEMA. Lecture notes in mechanical engineering, Singapore pp: 201-208.
14. Hemavathi S (2020) Li-ion battery health estimation based on battery internal impedance measurement, 1st National Conference on Innovations in

Sustainable Energy and Technology (ISET) pp: 183-193.

15. Hemavathi S (2017) Cloud computing and power systems applications-an overview, Nanoscience and Nanotechnology pp: 118-125.
16. Hemavathi S, Manohar S (2019) Microgird short circuit studie, IEEE Xplore pp: 1-6.
17. Hemavathi S (2021) Overview of cell balancing methods for Li-ion battery technology, Energy Storage 3: 1-12.
18. Hemavathi S (2020) Modeling of analog battery management system for single cell lithium ion battery, Energy Storage, Wiley 3: 1-9.
19. Hemavathi S (2019) Modeling and estimation of lithium ion battery state of charge using intelligent techniques, Advances in power and control engineering, Book Series: lecture notes in electrical engineering, Chapter 12, 609: 157-172.
20. Hemavathi S (2021) Modeling and energy optimization of hybrid energy storage system, Hybrid renewable energy systems, Book Series: Advances in renewable energy, Chapter 4, pp: 97-114.
21. Hemavathi S (2021) Li-ion battery health estimation based on battery internal impedance measurement, Innovations in sustainable energy and technology, Book Series: Advances in sustainability science and technology, 1st Edition, Chapter 17, pp: 183-193.

Author Affiliations

Top

[1]CSIR-Central Electrochemical Research Institute (CECRI), Chennai, India

[2]Department of Electrical Engineer, Academy of Scientific and Innovative Research, Ghaziabad, Uttar Pradesh, India

[3]Department of Computer Engineering, Madhuben and Bhanubhai Patel Institute of Technology, CVM University, Vidya Nagar, Anand, India

[4]Department of Mechanical Engineering, MJP Rohilkhand University, Bareilly, Utter Pradesh, India

[5]Department of Electrical Engineering, MJP Rohilkhand University, Bareilly, India

[6]Deptartment of Electrical Information, Bhilai Institute of Technology, Durg, India

[7]Department of Electrical Engineering, SRK University, Bhopal, India