FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

Power Quality Analysis of Fuzzy DVR based Hybrid Solar PV-PEMFC System Under Severe Disturbance

Mohamed Iqbal. M[1]*, Senthilkumar M[2], Zahira. R[3], Ganesh. C[4], Balaji V[5] and Vishalini G[6]

[1,2]*Department of Electrical and Electronics Engineering, PSG Institute of Technology and Applied Research, Coimbatore, Tamil Nadu, India, mohdiq.m@gmail.com*

[3]*Department of Electrical and Electronics Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai, India, zahirajaved@gmail.com*

[4]*Department of Computer and Communication Engineering, Rajalakshmi Institute of Technology, Chennai, India, c.ganesh.srit@gmail.com*

[5]*Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India, mailbalajiv@gmail.com*

[6]*R&D Division-Mechatronics, Lakshmi Machine Works Limited, Coimbatore, Tamil Nadu, India; vishalinijulu@gmail.com*

***Correspondence:** Mohamed Iqbal. M; mohdiq.m@gmail.com

ABSTRACT- Hybrid Energy System (HES) is becoming popular as it is identified as the most safe, sustainable, and long-term option for energy management. The grid-connected power network is vulnerable to frequent interruptions, which can lead to instability and a huge blackout. Furthermore, the presence of switching devices in industrial and domestic applications causes disturbances such as voltage swell/sag, waveform distortion, interruptions, impulsive voltage, and so on. Dynamic voltage restorer, known as a modern power compensating device, is cost effective, compact in size and can handle more energy capacity than DTSATCOM and UPFC. Hence for addressing the power quality issues in hybrid solar photovoltaic (PV)-proton exchange membrane fuel cells (PEMFC) system, dynamic voltage restorer (DVR) has been designed in this paper. As the fuzzy logic technique can provide flexible solutions in the case of uncertainty, fuzzy logic-based controller has also been employed with DVR to regulate the firing pulses of a PWM generator. Based on the simulation results obtained using fast fourier transform (FFT) analysis in MATLAB/Simulink, the dynamic performance of HES against the most important contingency condition or three phase faults is analyzed in detail. Further, the impact of DVR on power quality improvement under severe fault has also been demonstrated in this research work. On analyzing the total harmonic distortion (THD) values of HES under heavy disturbances, the fuzzy controlled dynamic voltage regulator (FCDVR) is identified as an efficient control mechanism for enhancing power quality in grid-connected HES.

Keywords: Fast Fourier transform, Fuzzy controlled dynamic voltage restorer, Hybrid energy system, Photo voltaic, Proton exchange membrane fuel cell, Total harmonic distortion.

ARTICLE INFORMATION

Author(s): Mohamed Iqbal. M, Senthilkumar M, Zahira. R, Ganesh. C, Balaji V and Vishalini G;

Received: 15/11/2022; **Accepted**: 07/03/2023; **Published**: 15/03/2023;

e-ISSN: 2347-470X;

Paper Id: IJEER 1511-05;

Citation: 10.37391/IJEER.110121

Webpage-link:

https://ijeer.forexjournal.co.in/archive/volume-11/ijeer-110121.html

crossref member CROSSREF.ORG THE CITATION LINKING BACKBONE

Publisher's Note: FOREX Publication stays neutral with regard to Jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

Global demand for the production of renewable energy is rising in the modern world. Since renewable energy sources are inherently intermittent, the idea of a hybrid renewable energy system has been created to satisfy the power requirements [1]. Especially the hybrid energy holds a particular potential for most of the developing and remote countries [2] and [3]. On the other hand, traditional energy sources create ecological problems like ozone layer depletion, carbon emissions, acid rain, climate change brought on by greenhouse gas emissions, and radioactive chemical releases. To overcome these conflicts hybrid energy sources are focused to ensure sustainable power delivery [4]. Pairing the solar PV module with battery can also lead to the better efficiency and reliable power output [5]. In relation to the environment, solar photovoltaic (PV) and fuel cell systems will be the future technology [6]. Towards the sustainable energy generation possibilities, the research work proposed in this paper examines a grid-connected hybrid energy system (HES) which comprises of a PV module and a proton exchange membrane fuel cells (PEMFC) system. In real time systems, comparing all the other power quality problems, voltage sag/dip has more severe impact in HES under distributed and smart-grid environment [7-10].

Sustainable energy delivery system is required to provide the consumers with a constant flow of electricity at the specified frequency and magnitude. But in reality, the power quality has been affected because of the increased use of power electronic based switching devices in industrial and household appliances. Switching devices and electronic control-based drives, for instance, are responsible for power quality problems such as voltage drops, surges, and distortions [11]. In order to suppress these power quality issues in the distribution side, number of flexible AC transmission system (FACTS) devices namely the distribution static synchronous compensator (DSTATCOM), DVR, and united power quality conditioner (UPQC) are being used [12-14]. Comparatively DVR is cost effective and compact in size and has more energy capacity than DSTACOM, UPFC etc. [15]. Hence it is proposed to develop fuzzy based DVR for improving the power quality of interconnected HES. A distributed static synchronized series compensator (SSSC) with a power electronic foundation is referred to as a DVR. Voltage swell and drop reduction is the primary purpose of a DVR [16]. The DVR can alleviate power quality problems by reducing the load voltage to pre-fault levels [12]. It can also eliminate the harmonics and reduce voltage transients and fault current limitations [17]. When a voltage sag or swell occurs, the DVR injects voltage to bring the load voltage back to normal [18]. It does this by exchanging active and reactive power with the load. At both the low and medium voltage levels, DVR can be employed to safeguard high power applications against voltage sags [19, 20]. *Section 2* of this paper describes about the hybrid solar PV–PEMFC energy system and its modelling. DVR modeling has been presented in *Section 3*. *Section 4* deals about the development of fuzzy controlled DVR. The suggested system's performance is evaluated using MATLAB/Simulink. Total Harmonic Distortion (THD) is considered for analyzing 3- phase symmetrical fault with different cases *i.e.* (*i*) Without using DVR (*ii*) With DVR and (*iii*) With Fuzzy Controlled DVR and identified the impact of severe three phase fault on power quality of hybrid energy system. Simulation results of all these cases are furnished in *Section 5*.

2. PROPOSED HYBRID ENERGY SYSTEM

The majority of power quality issues caused by various fault scenarios can be resolved using DVR by creating an acceptable voltage quality level [21, 22]. A DC/DC boost converter and a DC/AC inverter are used to connect the solar PV and PEMFC energy sources to the utility grid in the suggested hybrid energy system, as illustrated in *figure 1*.

A DC/DC boost converter is used to increase the output from solar PV and the PEM Fuel Cell (PEMFC). Then the boost converter output is given to the DC/AC converter from which the DC voltage is inverted and the load voltage is stepped up. The phase voltages are converted into their d-q components by the fuzzy-based controller, which then generates a PWM signal based on the amplitude and angle of the d-q components [15] and [23].

Under normal work conditions, the 'd' axis voltage might be 1.0 p.u. while the 'q' axis voltage might be 0.0 p.u. The fuzzy array is used to provide the reference signal for each phase. The supply voltage for each phase is converted to a unit, and the error is then calculated. The suggested system manages the load side voltage as a result by injecting voltage into the system.

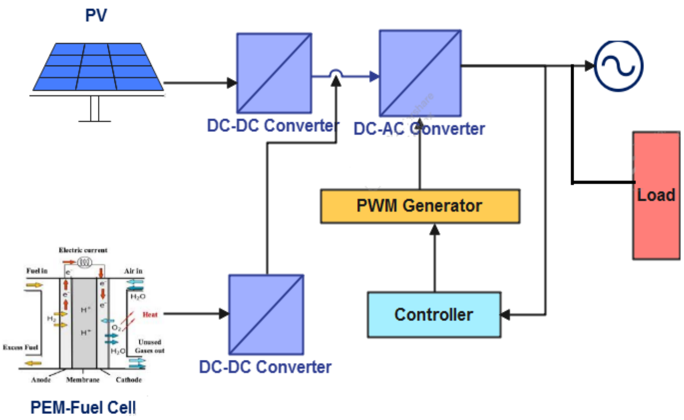

Figure 1: Proposed Hybrid Energy System with Solar PV and PEMFC

3. MODELLING OF HYBRID ENERGY SYSTEM

Hybrid energy system is highly reliable and can help improving the standard of living in remote areas [2]. Many power quality issues may be realized when this proposed system is connected with the grid. To overcome this problem, appropriate modeling and selection of controller become very important. The MATLAB/Simulink model for dynamic analysis, has also been presented along with the mathematical modelling of the solar PV system and the PEMFC system.

3.1 Modelling of Solar PV System

Solar panels are used as one of the green energy sources due to its everlasting nature. The solar panels are made up of semiconductors forming a photovoltaic (PV) cell. The photons falling on the crystalline silicon solar panel releases free electrons producing electricity [24]. Due to the irregular temperature and the solar irradiation, the grid connected solar PV system has many voltage fluctuations. The solar cell current (I) is obtained based on the theoretical operation of solar PV cells with its respective equivalent circuit. It consists of a perfect PV cell, a current source, a diode, and resistance that is connected in series and shunt [25]. Solar PV cell model is shown in *figure 2*. From solar PV equivalent circuit and by applying Kirchhoff's law, the current equations are obtained. Solar cell current is expressed in Eq. (1). Based on the rate of change of temperature (ΔT), nominal short circuit current $I_{n,sc}$ and irradiance (G), the output current of PV is derived from Eq. (2). Diode saturation current (I_O) is influenced by operating temperature of open circuited solar cell (T_{nop}), nominal saturation current (I_{ns}).

The diode saturation current (I_O) is obtained by calculating the change in temperature value ΔT i.e. the difference between reference and operating temperature of solar cell, multiplied with nominal saturation current ($I_{0,n}$), ideality factor (a), charge of electron (q) and band gap energy of semiconductor (E_g) as in *eq. (3)*.

Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

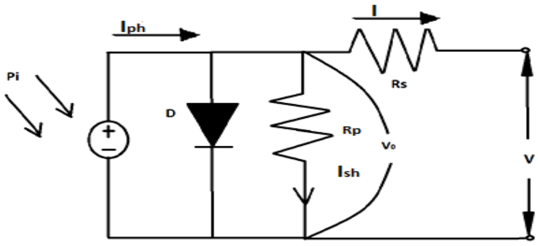

Figure 2: Solar PV cell Model

$$I = I_{pv} - I_0\left[\exp\left(\frac{q(V+IR_S)}{a*k*T}\right)-1\right] - \left[\frac{V+IR_S}{R_{sh}}\right] \quad (1)$$

$$I_{pv} = \frac{G}{G_{ref}}\left(I_{n,sc}*\left[\frac{R_{sh}+R_S}{R_{sh}}\right]+K_i*\Delta T\right) \quad (2)$$

$$I_O = \frac{I_{sc,n}+K_i\Delta T}{\left[exp\left(\frac{V_{oc,n}+K_V\Delta T}{aV_t}\right)-1\right]}\left(\frac{T_{nop}}{T_{ref}}\right)^3 * exp\left[\frac{qE_g}{ak}\left[\frac{1}{T_{nop}}-\frac{1}{T_{ref}}\right]\right] \quad (3)$$

Based on the modeling parameters of solar cell as required for the solar PV system, MATLAB/Simulink has been created for the solar photovoltaic system and shown in *figure* 3.

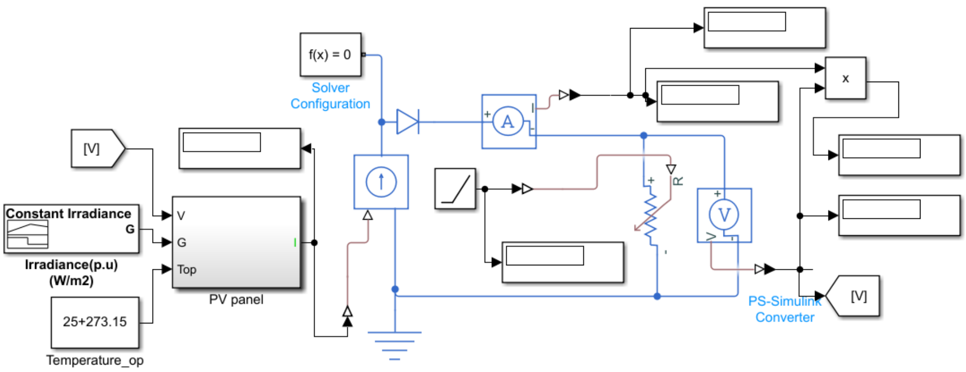

Figure 3: MATLAB/Simulink model of solar PV system

3.2 Modelling of Fuel Cell System

The chemical energy, i.e., oxygen and hydrogen, are converted into electrical energy at the input side [26]. The PEMFC is utilized by numerous researchers due to its affordability and compactness [27] and [28]. *Figure 4* shows how MATLAB/Simulink has been used to model the proposed HES's PEMFC.

The flow rate selector is connected to the fuel cell stack via three-way single pole switches and the output of PEMFC is viewed by connecting across the DC/DC boost converter. The flow rate, efficiency, hydrogen and oxygen utilization and its consumption can be obtained from Simulink model. In addition, the fuel cell's voltage and current signals, DC/DC boost converter's voltage and current signals are also obtained. The hybrid energy system combining solar PV and PEMFC are interconnected with the grid as shown in *figure 5*. For power quality improvement, DVR has been proposed whose modelling is presented in *Section 4*.

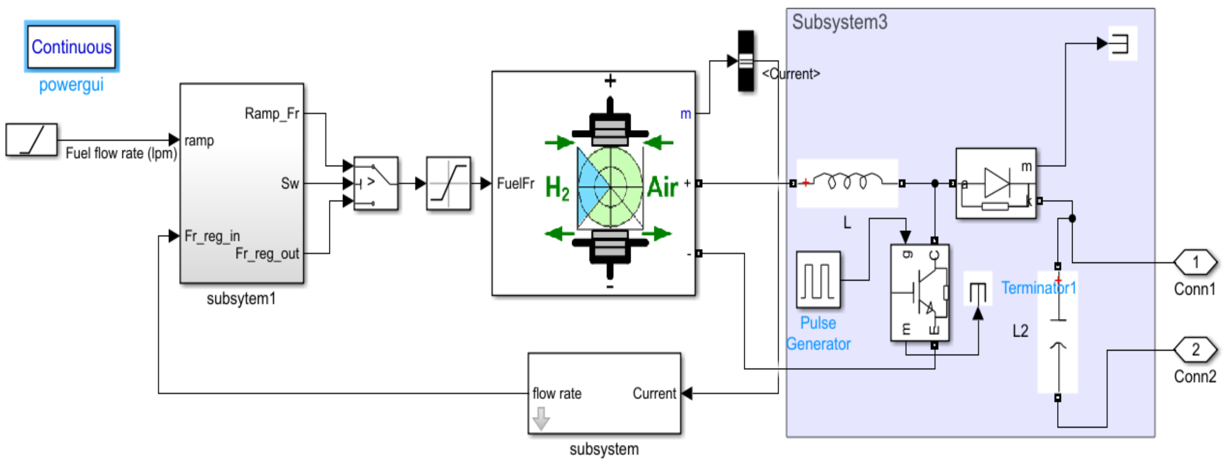

Figure 4: MATLAB/Simulink model of PEMFC

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

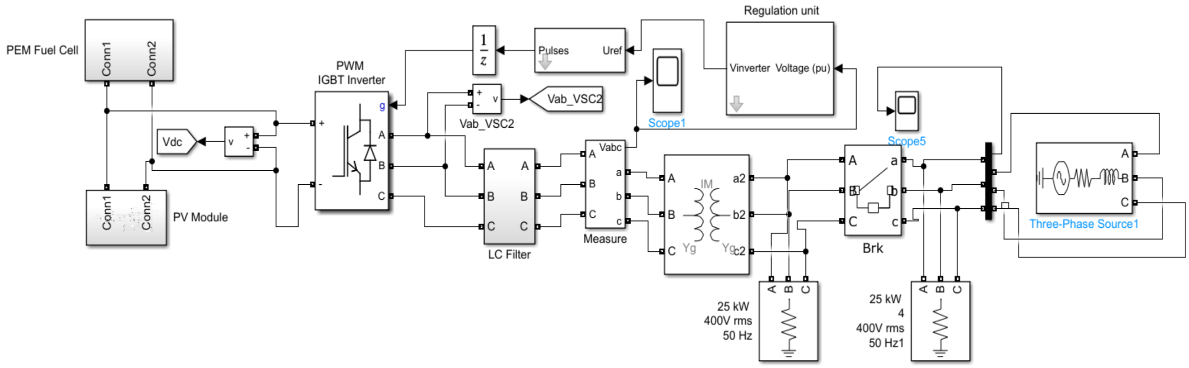

Figure 5: MATLAB/Simulink model of Solar PV-PEMFC Hybrid Energy System

4. MATHEMATICAL MODELLING OF DVR

According to the recently developed concept of customized power devices, dynamic voltage restorer, a series-connected solid-state device, injects voltage into the system to maintain the load side voltage [29]. It is frequently located at the point of common coupling (PCC) between the supply and the important load feeder. The DVR is a contemporary specialized power tool that corrects voltage sag and voltage swell [27]. Furthermore, it can aid in the reduction of harmonics, voltage transients, and fault current restrictions [15].

The system impedance, Z_S in DVR is decided only by the load bus fault level. *Figure 6* [30] depicts the DVR equivalent structure. At the time of voltage disturbance on the load side injection, transformer in DVR injects voltage, V_{dvr}, in order to maintain load voltage magnitude V_l as expressed in Eq. (4).

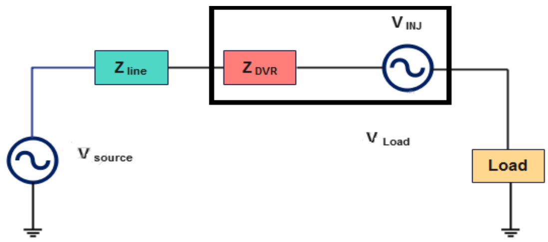

Figure 6: Equivalent structure of DVR

If the system voltage (V_s) is dropped, the DVR will inject the voltage (V_{dvr}) as expressed in Eq. (5) to restore the system voltage. Load current can be obtained as expressed in Eq. (6). The output voltage of DVR in polar form is represented as shown in Eq. (7).

$$V_{dvr} + V_s = V_l + Z_s I_l \quad (4)$$

$$V_{dvr} = V_l + Z_s . I_l - V_s \quad (5)$$

$$I_l = \frac{(P_i + jQ_i)}{V_i} \quad (6)$$

$$V_{dvr}\angle\alpha = V_l\angle 0 + Z_s . I_l\angle(\beta-\theta) - V_s\angle\delta \quad (7)$$

Where α, β and δ are the angle of V_{dvr}, Z_s and V_s respectively. The power factor angle, θ is given in Eq. (8). Finally the power injected by DVR is shown in Eq. (9).

$$\theta = tan^{-1}\left(\frac{Q_i}{P_i}\right) \quad (8)$$

$$P_{dvr} = V_{dvr} . I_l \quad (9)$$

The DVR control circuit is modeled in MATLAB/Simulink, and the load voltage is sent to the 3-phase harmonic analyzer block as an input. The amplitude and phase components of the incoming voltage signal are evaluated, and the magnitude component is supplied to the difference block. The voltage is then compared to the intended voltage level of 1pu, which is represented by a constant block. The output of the difference block is the difference of the two voltage levels. The difference is multiplied by the 'sine' function and sent to the pulse generator. The pulse generator produces firing pulses of the appropriate magnitude level to act as the gate signal inverter for the DC/AC converter. Since it is necessary to recognize and mitigate the existence of voltage sag in the system, the fuzzy based controller has been designed as described in *Section 5*.

5. FUZZY EXPERT SYSTEM FOR DVR

Efficiency of any system depends on the controller used, as it only tries to maintain (pre-sag or swell values) or reduce the sag, swell or the harmonics by compensating the voltage level [31]-[32]. The control procedure for DVR and the steps involved for developing the fuzzy controlled DVR has been presented below [33].

5.1 DVR Control Logic

Prime function of the controller in a DVR is to detect voltage sag in the system [34] and create trigger pulses for the PWM inverter [23]. *Figure 7* shows the fundamental functioning of DVR under voltage variations [35]. Initially, the line voltage (V_{abc}) is converted into 'dq' components and is been compared with the set reference voltage (V_{ref}) values in the 'dq' reference frame. The error between V_{abc} and V_{ref} is calculated and converted into unit sinusoidal waveforms which is in-phase with the main supply voltage without any quality issues. In addition, the usage of PWM inverter reduces the harmonics and control output voltages.

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

The three phase line voltages V_a, V_b and V_c are observed and converted into direct, quadratic and zero components using abc-dq_0 transformation block in DVR. In dq_0 transformation block, the 3-phase static coordinate system i.e. V_a, V_b, V_c as shown in *eq. (10), (11) and (12)* is transformed to the "dq" rotary coordinate system V_d, V_q and V_o as in *eq. (13), (14) and (15)* respectively. This dq_o technique provides depth (d) and phase shift (q) of sag voltage information with start and end time [17].

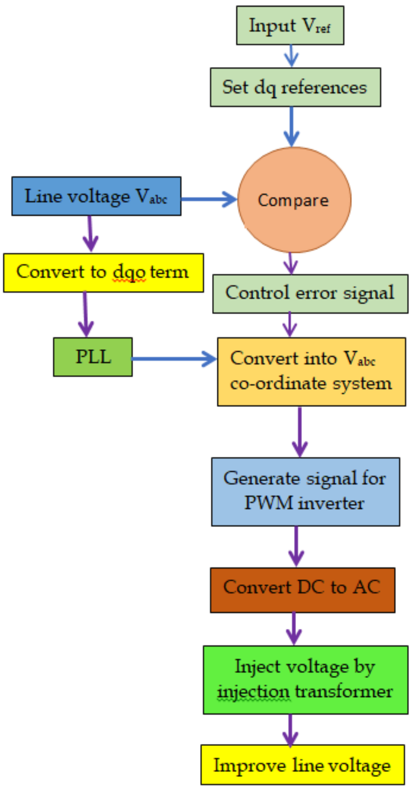

Figure 7: Operation of DVR under voltage deviations

$$V_a = [V_d sin(wt) + V_q \cos(wt) + V_o] \quad (10)$$

$$V_b = [V_d \sin\left(wt - \tfrac{2\pi}{3}\right) + V_q \cos(wt - \tfrac{2\pi}{3}) + V_O] \quad (11)$$

$$V_c = \left[V_d \sin\left(wt + \tfrac{2\pi}{3}\right) + V_q \cos\left(wt + \tfrac{2\pi}{3}\right) + V_O\right] \quad (12)$$

$$V_d = \tfrac{2}{3}\left(V_a \sin \omega t + V_b \sin(\omega t - \tfrac{2\pi}{3}) + V_c \sin(\omega t + \tfrac{2\pi}{3})\right) \quad (13)$$

$$V_q = \tfrac{2}{3}\left(V_a \cos \omega t + V_b \cos(\omega t - \tfrac{2\pi}{3}) + V_c \cos(\omega t + \tfrac{2\pi}{3})\right) \quad (14)$$

$$V_0 = \tfrac{1}{3}\left(V_a + V_b + V_c\right) \quad (15)$$

Since the fixed gain controller cannot be used for wide range of operating conditions, fuzzy logic controller is established in this paper for improving the power quality as presented below.

5.2 Fuzzy Controlled DVR

Dr. Lotfi. A. Zadeh introduced fuzzy set theory in the 1960s [36]. One of the most effective fuzzy set theory procedures is the Fuzzy Logic Controller. The fuzzy set theory uses language variables rather than numerical values. This control strategy is based on quality control criteria and depends on human capacity to comprehend system behavior [37]. Fuzzy is predicated on 'degrees of truth' between 0 and 1 (false/true) instead of true or false.

The proposed system uses triangular membership functions as depicted in *Figure 8* for the input and output signals of error signals-d and error signals-q. The error signal (e) and change in error (ce) as obtained from the reference and actual voltage as given in *eq. (16) and (17)* respectively. These are input signals for fuzzy control system.

$$Errror(e) = V_{ref} - V_{abc}(p.u) \quad (16)$$

$$Error\ rate\ (ce) = e(n) - e(n-1) \quad (17)$$

For output signals and input signals, the five linguistic fuzzy levels namely Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) are selected [35]. Then, as indicated in *table 1*, a fuzzy rule base is constructed using the expertise of prior knowledge called expert information. Fuzzy controlled DVR model which is utilized to improve power quality in the proposed HES is illustrated in *figure 9*.

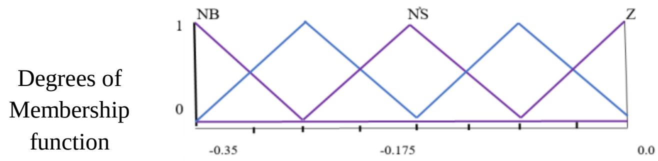

Figure 8: Input membership function for fuzzy logic controller

Table 1: Fuzzy rules for DVR control of HES

ce \ e	NB	NS	Z	PS	PB
NB	Z	PS	PS	PB	PB
NS	NB	Z	NS	PB	PB
Z	NB	NB	Z	PS	PB
PS	NB	NB	NS	Z	PS
PB	NB	NB	NS	NS	Z

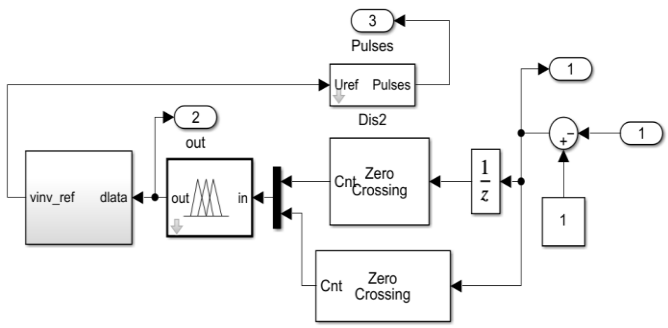

Figure 9: Fuzzy logic-based DVR control circuit

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

Initially crisp values are converted into crisp sets and they are later converted into fuzzy quantities. The fuzzy quantities are converted into fuzzy sets after discretization and normalization. Later, using membership functions they are converted into primary fuzzy sets. Finally, the defuzzification is done after the composition of fuzzy relation [34],[37] and [38]. Then SIMULINK model of HES is implemented with FCDVR. The performance of controller for symmetrical fault condition with/without DVR and FCDVR has been tested and the results are furnished in *Section 5*.

6. RESULTS AND DISCUSSION

The dynamic simulation performance of solar PV-PEMFC is obtained and the impact of DVR in improving the power quality is analyzed in this Section. Initially, the proposed solar PV-PEMFC system is simulated and the response is obtained for symmetrical three phase fault using MATLAB/Simulink. The proposed system's output voltage waveform and frequency spectrum for a symmetrical three-phase fault are obtained and presented in *figures 10* and *11*, respectively. The THD value for the three-phase fault without DVR controller is found to be 79.88%. Such a huge harmonics has been generated as an effect of the severe three-phase fault.

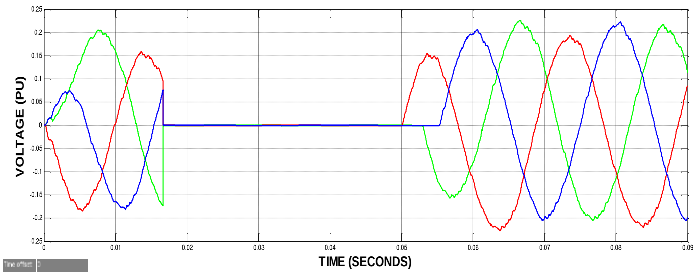

Figure 10: Waveform of the HES's output voltage without the DVR

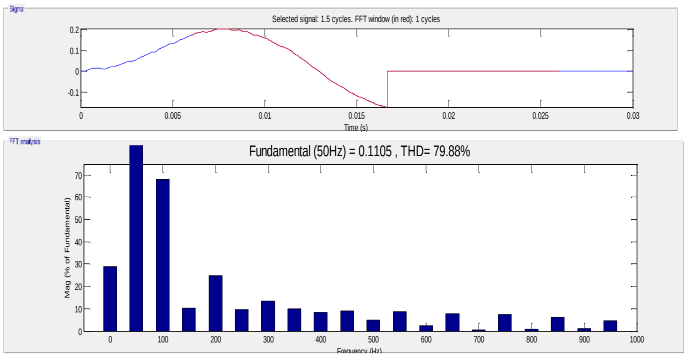

Figure 11: Output voltage frequency spectrum without DVR

For power quality enhancement, DVR has been incorporated in the proposed system and enhance the dynamic behavior. *Figures 12* and *13* show the output voltage and frequency spectrum, respectively. It is found that the THD value with DVR is improved to 58.86%. It also witnesses that the DVR can be used for dynamic stability improvement.

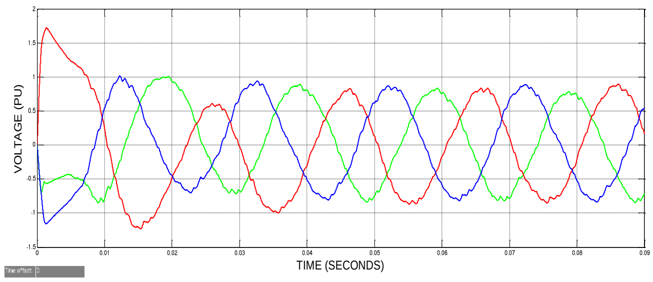

Figure 12: HES output voltage waveform with DVR

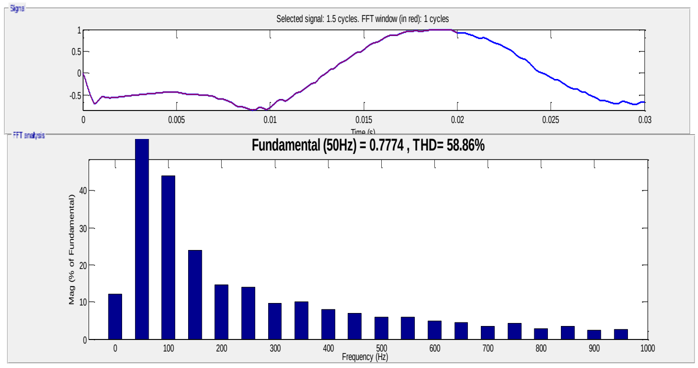

Figure 13: Frequency spectrum of output voltage with DVR

Later, the Fuzzy Controlled DVR (FCDVR) has been developed as explained in Section 5.2 for the **proposed** solar PV-PEMFC Hybrid Energy System. The output voltage waveform and frequency spectrum with FCDVR **controller** are shown in *figures 14* and *15* respectively.

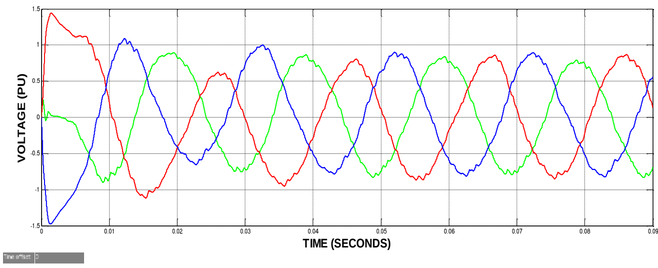

Figure 14: HES output voltage waveform with FCDVR

It has been observed from the simulation results that the THD value of HES under contingency status i.e. severe three-phase fault occurrence is reduced drastically to 39.28% by using FCDVR. It indicates that the FCDVR proposed for the hybrid energy system mitigates the harmonics and improves the power quality. When the harmonic levels are compared using THD values, it is clear that the Fuzzy Controlled DVR (FCDVR) is an effective controller for improving power quality in the grid-connected solar PV-PEMFC Hybrid Energy System. The investigation of a hybrid renewable energy system against a severe three-phase fault shows that the severity of the fault has a significant impact on the system's performance. This paper also shows that the effectiveness of the controller needs to be strengthened for the harmonic mitigation in grid-connected operation against the sever fault.

International Journal of
Electrical and Electronics Research (IJEER)
Open Access | Rapid and quality publishing
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

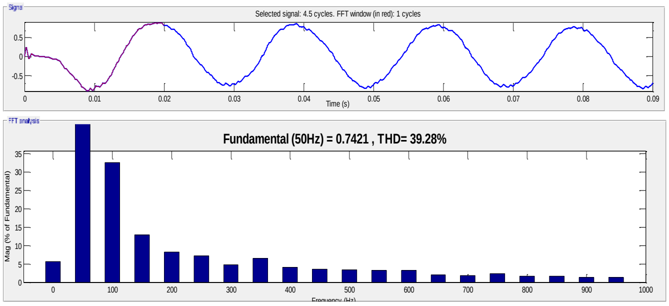

Figure 15: Frequency spectrum of output voltage with FCDVR

7. CONCLUSION

In this paper, the modeling of solar PV and PEMFC system using MATLAB/Simulink has been presented and the hybrid energy system is developed. Since the dynamic voltage restorer is more advantageous than DTSATCOM and UPFC, review, modelling and operation of dynamic voltage restorer with the scope of research in using DVR for power quality improvement are presented in detail. In this research, the fuzzy set theory based fuzzy control approach is utilized to improve power quality in a hybrid solar PV-PEMFC energy system in a contingency scenario. MATLAB/Simulink model of proposed hybrid system is simulated and the output voltage waveform frequency spectrums are analyzed based on THD values. The dynamic performance is analyzed in three different cases viz., without DVR, with DVR and with FCDVR. Because of the severe three-phase fault, the proposed HES without DVR yields the huge THD value of 79.88%. This level of harmonics present in system may damage the equipment and hence the entire system itself. Even after implementing DVR into the system, it could help to reduce THD value by 58.86% and presence of FCDVR has improved the power quality to the greater extent by reducing THD value to 39.28%. Such a huge impact on harmonics is caused due to the severity of the fault. Based on the analysis, FCDVR is identified as an intelligent control scheme for Hybrid Energy System (HES) yielding as an efficient solution for mitigating voltage sag, harmonics for symmetrical three phase fault. In future, the same network can be implemented for different combinations of hybrid energy systems with distinct custom power devices, varying the controller module in order to suppress the harmonics stress to the greater extent.

Author Contributions

“Conceptualization, **Mohamed Iqbal. M and Vishalini G**; methodology, **Mohamed Iqbal. M, Vishalini G**; validation, **Zahira. R**; formal analysis, **Mohamed Iqbal. M**; investigation, **Mohamed Iqbal. M,Vishalini G**.; resources, **Mohamed Iqbal. M**; data curation, **Mohamed Iqbal. M. Vishalini G**; writing—original draft preparation, *** Mohamed Iqbal. M,Vishalini G**; writing—review and editing, **Zahira. R., Balaji V Senthilkumar M and Ganesh. C**; visualization, **Mohamed Iqbal. M**; supervision, **Mohamed Iqbal. M**; project administration, **Mohamed Iqbal. M, Zahira. R., Ganesh. C**. All authors have read and agreed to the published version of the manuscript”.

Funding

This research received no external funding.

Acknowledgments

Authors would like to extend the heart felt gratitude to The Management and Principal for extending their support towards research promotion and encouragement for working towards societal cause.

Conflicts of Interest

The authors declare no conflict of interest.

APPENDIX A

Solar PV model and DVR model parameters

Symbol	Parameters	Unit
I0	Diode saturation current	*Amp*
k	Boltzmann’s constant	J/K
Ipv	Photo voltaic current	*Amp*
In,sc	Nominal short circuit current	*Amp*
Eg	Band gap energy of the semiconductor	*eV*
q	Electron charge	*coulumb*
Tref	Nominal temperature	*K*
$T_{n,op}$	Nominal operating temperature	*K*
Ki	Short circuit current of cell	w/m^2
a	Ideality factor of diode	-
Ins	Nominal saturation current	*Amp*
V_{dvr}	DVR voltage	*V*
Ir	Solar irradiation	w/m^2
I	Current output of PV module	*Amp*
N_P	Number of PV modules connected in parallel	-
R_s	Series resistance	*ohms*
R_{sh}	Shunt resistance	*ohms*
N	Ideality factor of diode	-
N_s	Number of PV modules connected in series	-
I_{sh}	Short circuit current	*Amp*
V_t	Diode thermal voltage	*V*
V_l	Load voltage	V
I_l	Load current	*Amp*
Z_s	System impedance	*ohms*
V_s	System voltage during fault condition	*V*
$V_{n,oc}$	Nominal open circuit voltage	V
G	Actual radiation	KW/m^2
G_{ref}	Nominal radiation	KW/m^2
ΔT	Difference between reference and operating temperature of solar cell	K
Θ	Load power angle	-

REFERENCES

[1] Bhandari, B., Lee, KT., Lee, GY. et al., “Optimization of hybrid renewable energy power systems: A review”, Int. J. of Precis. Eng. and Manuf.-Green Tech. 2015, 2: 99–112.

[2] Liu, X., Wang, P. and Loh, P.C., “A hybrid AC/DC microgrid and its coordination control”, IEEE Transactions on smart grid, 2011, 2(2): 278-286.

[3] Ye, C., Miao, S., Lei, Q. and Li, Y., “Dynamic energy management of hybrid energy storage systems with a hierarchical structure”, Energies, 2016, 9(6): 395.

[4] Allahvirdizadeh, Y., Shayanfar, H., &ParsaMoghaddam, M., “A comparative study of PI, fuzzy-PI, and sliding mode control strategy for

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 1 | Pages 148-155 | e-ISSN: 2347-470X

battery bank SOC control in a standalone hybrid renewable system", International Transactions on Electrical Energy Systems, 2019, e12181.

[5] Ramasamy, M. and Thangavel, S., "Experimental verification of PV based Dynamic Voltage Restorer (PV-DVR) with significant energy conservation", International Journal of Electrical Power & Energy Systems, 2013, 49: 296-307.

[6] Tawalbeh, M., Al-Othman, A., Kafiah, F., Abdelsalam, E., Almomani, F., & Alkasrawi, M. "Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook", Science of The Total Environment, 2021, 759, 143528.

[7] Deepika G, Elakkiya M, Mohamed Iqbal M, "Harmonics Reduction using Multilevel Based Shunt Active Filter with SMES", International Journal of Engineering and Technology, April 2017, 9(2): 1001-1011.

[8] Mohamed Iqbal.M, Lakshmi Sankar.S, "Transient Stability enhancement of a Typical 2X30 MW Thermal Power Plant and Validation Through IEEE 9 Bus Test system – A Case study", Journal of Electrical Engineering, November 2016, 16(3): 9-18.

[9] Naderi, Y., Hosseini, S. H., Zadeh, S. G., Mohammadi-Ivatloo, B., Vasquez, J. C., & Guerrero, J. M. "An overview of power quality enhancement techniques applied to distributed generation in electrical distribution networks", Renewable and Sustainable Energy Reviews, 2018, 93: 201-214.

[10] Naderi, Y., Hosseini, S. H., Ghassemzadeh, S., Mohammadi-Ivatloo, B., Savaghebi, M., Vasquez, J. C., & Guerrero, J. M., "Power quality issues of smart microgrids: applied techniques and decision-making analysis", In Decision making applications in modern power systems, Academic Press, 2020: 89-119.

[11] Ribeiro, E., Cardoso, A.J.M. and Boccaletti, C., "Fault-tolerant strategy for a photovoltaic DC-DC converter", IEEE Transactions on Power Electronics, 2012, 28(6): 3008-3018.

[12] Mohammed, S.A., Cerrada, A.G., Abdel-Moamen, M.A. and Hasanin, B., "Conventional dynamic voltage restorer (DVR) for mitigation of voltage sags in power distribution systems", International Journal of Advances in Engineering & Technology, 2013, 6(1): 415.

[13] Arya, S. R., Patel, M. M., Alam, S. J., Srikakolapu, J., & Giri, A. K. "Phase lock loop–based algorithms for DSTATCOM to mitigate load created power quality problems", International Transactions on Electrical Energy Systems, 2020, 30(1), e12161.

[14] Mohamed, S. A., "Enhancement of power quality for load compensation using three different FACTS devices based on optimized technique", International Transactions on Electrical Energy Systems, 2019, e12196.

[15] Dey, S., "Comparison of DVR and D-STATCOM for Voltage Quality Improvement", International Journal of Emerging Technology and Advanced Engineering, 2014, 4(10): 187-193.

[16] Nielsen, J.G., Newman, M., Nielsen, H. and Blaabjerg, F., "Control and testing of a dynamic voltage restorer (DVR) at medium voltage level", IEEE Transactions on power electronics, 2004, 19(3): 806-813.

[17] Omar, R., & Rahim, N. A., "Modeling and simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR)", Australasian Universities Power Engineering Conference, IEEE, 2008: 1-5.

[18] Shi, J., Tang, Y., Yang, K., Chen, L., Ren, L., LI, J. and Cheng, S., "SMES based dynamic voltage restorer for voltage fluctuations compensation", IEEE transactions on applied superconductivity, 2010, 20(3): 1360-1364.

[19] Arrillaga, J.O.S., Bollen, M.H. and Watson, N.R., "Power quality following deregulation", Proceedings of the IEEE, 2000, 88(2): 246-261.

[20] Boonchiam. P and Mithulananthan N., "Diode-clamped multilevel voltage source converter based on medium voltage DVR", International Journal of Electrical Power and Energy Systems Engineering, 2008, 1(2): 62-67.

[21] Vilathgamuwa, M., Perera, A.R., Choi, S.S. and Tseng, K.J., "Control of energy optimized dynamic voltage restorer", In IECON'99. Conference Proceedings. 25th Annual Conference of the IEEE Industrial Electronics Society (Cat. No. 99CH37029), IEEE, 1999, 2: 873-878.

[22] Woodley, N.H., Morgan, L. and Sundaram, A., "Experience with an inverter-based dynamic voltage restorer", IEEE Transactions on Power Delivery, 1999, 14(3): 1181-1186.

[23] STUMP, M.D., KEANE, G.J. and LEONG, F.K., "The role of custom power products in enhancing power quality at industrial facilities", In Proceedings of EMPD'98. 1998 International Conference on Energy Management and Power Delivery (Cat. No. 98EX137), IEEE, 1998, 2: 507-517.

[24] Teke, A., Bayindir, K. and Tümay, M., "Fast sag/swell detection method for fuzzy logic controlled dynamic voltage restorer", IET generation, transmission & distribution, 2010, 4(1): 1-12.

[25] Keles, C., Alagoz, B.B., Akcin, M., Kaygusuz, A. and Karabiber, A., "A photovoltaic system model for MATLAB/Simulink simulations", In 4th International Conference on Power Engineering, Energy and Electrical Drives, IEEE, 2013: 1643-1647.

[26] Spiegel, C., "PEM fuel cell modeling and simulation using MATLAB", Elsevier, 2011.

[27] Samal, S. and Hota, P.K., "Design and analysis of solar PV-fuel cell and wind energy based microgrid system for power quality improvement", Cogent Engineering, 2017, 4(1), p.1402453.

[28] Jayaprakash, P., Singh, B., Kothari, D.P., Chandra, A. and Al-Haddad, K., "Control of reduced-rating dynamic voltage restorer with a battery energy storage system", IEEE transactions on industry applications, 2013, 50(2): 1295-1303.

[29] Domijan, A., Montenegro, A., Keri, A.J. and Mattern, K.E., "Custom power devices: An interaction study", IEEE transactions on Power Systems, 2005, 20(2): 1111-1118.

[30] Norouzi, M. A., Olamaei, J., & Gharehpetian, G. B., "Compensation of voltage sag and flicker during thermal power plant turbo-expander operation by dynamic voltage restorer", International Transactions on Electrical Energy Systems, 2016, 26(1): 16-31.

[31] Kumari, P. and Garg, V.K., "Power Quality Enhancement using Dynamic Voltage Restorer (DVR): An Overview", International Journal of Scientific and Research Publications, 2013, 3(8): 1-8.

[32] Taghizadeh, S., Mei Lin Tan, N., &Karimi-Ghartemani, M., "Study of fuzzy based control algorithm for dynamic voltage restorer", International Transactions on Electrical Energy Systems, 2015,25(12): 3600-3617.

[33] Jowder, F. A. L., "Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation", IET generation, transmission & distribution, 2009, 3(6): 547-560.

[34] Gopinath, C., Yaashuwanth, C., Ramesh, R., Maglin, J.R. and Bosco Raj, T.A., "Analysis and mathematical model for restitution of voltage using dynamic voltage restorer", Mathematical Problems in Engineering, 2014.

[35] Mohamed Iqbal, M. and Joseph Xavier, R., "Fuzzy self-tuning PID controller for Speedtronic governor controlled heavy duty gas turbine power plants", Electric Power Components and Systems, 2014, 42(14): 1485-1494.

[36] Mustafa, M.I.M., Rayappan, J.X. and Jagannathan, K., "A neuro-fuzzy controller for grid-connected heavy-duty gas turbine power plants", Turkish Journal of Electrical Engineering & Computer Sciences, 2017, 25(3): 2375-2387.

[37] Prof. Kalyani Kurundkar and Dr. G. A. Vaidya (2021), Application of HFPSO-TOPSIS approach for optimally locating and sizing of reactive power compensating devices for voltage control ancillary service. IJEER 9(3), 16-26. DOI:10.37391/IJEER.090301.

[38] Miska Prasad and A.K Akella (2021), Comparison of Voltage Swell Characteristics in Power Distribution System. IJEER 4(3), 67-73. DOI: 10.37391/IJEER. 040302.