ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

# Experimental Validation of FPDM Controller for controlling and stabilizing the bus voltage of PV DC Microgrid

**Shipra Jain*, Rajesh Kr Ahuja, Anju Gupta**

*Department of Electrical Engineering, JC Bose University of Science and Technology, YMCA Faridabad India 121006*

**Abstract**. The proposed research paper deals with experimental validation of FPDM (Fuzzy-PI Dual Mode) controller in stabilizing and controlling of bus voltage of PV DC Microgrid (PVDCM). Due to non-linear characteristics of PV cells, conventional control method of voltage and current always show its incompetency in improving the system dynamic response and thus, the DC voltage deviation is hard to keep in limit. As a result, there is need of a new type of controller which can handle such type of issue and thus FPDM controller is proposed in this paper. This controller, make use of outer ring voltage to improve the performance of system during transient condition

i.e. when deviation of bus voltage is substantial. Further, an experimental validation has also been done for Initial Power up, Load surge and load plummet transient condition via PI controller, Fuzzy controller and FPDM controller to show the practical environment suitability of this designed controller.

***Keywords:*** FPDM controller, PVDCM, ESD, PI Controller, Fuzzy Controller, Renewable Energy

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## 1. Introduction

In case of PVDCM, DC bus voltage is used for determining the system stability (Yang Q et al. 2016, Li B 2017).and due to changing nature of solar irradiance the solar power output keeps on changing thus there is unpredictable power disturbances from the output of PVDCM resulting in fluctuation of bus voltage. These issues need to be addressed immediately for ensuring the stable operation (Karaaslan A. et al. 2020). An energy storage device is added into bus voltage through the help of bidirectional chopper (D.Xu 2018). This energy storage device (ESD) that is added is capable of storing energy depending upon the magnitude of bus voltage and hence increasing the robustness of system (H. Li et al. 2021, H. Xiao et al. 2014, López-Rodríguez R etal. 2021, Rawa M et al. 2020, B. Zhao et al. 2012). ESD generally employs dual closed loop voltage and current control strategy that makes use of bus voltage for controlling outer ring and current for controlling inner ring (Rana MM et al. 2015, A. Jahangir et al. 2018). But, this system was unable in limiting the fluctuation effectively. Various past work had been done over this as in (Nguyen T-T etal. 2015, B.Wei et al. 2019) by including feedforward control into conventional dual closed-loop control. When there is a change in load, it is found that feedforward control technique provide the enhanced dynamic response of DC converter and maintained the output voltage constant (H. Amiri et al. 2019) Further, a ripple compensation link is added in the inner ring so as to improve the dynamic response time and to improve the quality of systematic output power (B. Fan et al. 2019). But, it makes output current to lag behind the load as there is delay in ring of voltage and current. In case of power feedforward control, for controlling the variation of bus voltage, disturbance power is being supplied to control link (Tao H. 2022). This also helps in improving the system stability (Kayaalp I. 2016) as by feeding the disturbances power, fluctuation of bus voltage get reduce and also help in improving converter anti-load disturbance capability (Li Y et al. 2019). This strategy also helps in improving the system response time, which further helps in improving the system ability to control the variation in bus voltage. In the similar manner as that of current feedforward, this power feedforward also shows delay in relation to load disturbances which again proves its one of the limitations in accepting this controller in present time or in practical environment.

Feedforward control technique make use of collection of real time data, which makes the system costly and make the system less reliable. To compensate the above mentioned problem, a state observer and non-linear perturbation observer were incorporated into the control link (X. Li et al. 2019, A. Varshney et al. 2021). Thus, whenever magnitude is being assessed by state observer, no disturbance signal is being required. This model require lesser mathematical calculation, simple in construction, less noisy and thus less affects over the power quality of microgrid. Since, photovoltaic DC microgrid has high non-linearity (O. Ibrahim et al. 2017,
N. Varshney et al. 2020, I.Zaidi et al. 2015, Y. Sun et al. 2009, K.Yuan et al. 2008), the proposed research paper replaces the dual closed loop controller with FPDM controller. The originality and Novelty of proposed research paper are as:

- (H. Li et al. 2021, H. Xiao et al. 2014, López-Rodríguez R et al. 2021, Rawa M et al. 2020, B. Zhao et al. 2012) make use of ESD for controlling the bus voltage fluctuation, but this system fails in controlling the minor and major bus voltage deviation.
- To compensate the above-mentioned issue,

feedforward controller was being used as in in (Nguyen T-T et al. 2015, B.Wei et al. 2019, H. Amiri et al. 2019, B. Fan et al. 2019, Kayaalp I. 2016), but it makes output current to lag the load as there is delay in ring of voltage and current. Thus, this controller also has some limitation and failed in achieving the desired response.

- Further, in past work, a power feedforward controller was proposed (Tao H. 2022, Kayaalp I.2016, Li Y et al. 2019) to compensate the same problem as mentioned above, but it also shows delay in relation to load disturbances which again proves its one of the limitations in accepting this controller in present time or in practical environment.

To compensate the problem arises due to use of feedforward controller, a controller was proposed as in (X. Li et al. 2019, A. Varshney et al. 2021) which make use of state observer and non-linear perturbation, thus making the system construction easier and mathematical modelling easier, but this controller also lack in covering the high degree non-linearity produce by photovoltaic DC microgrid.

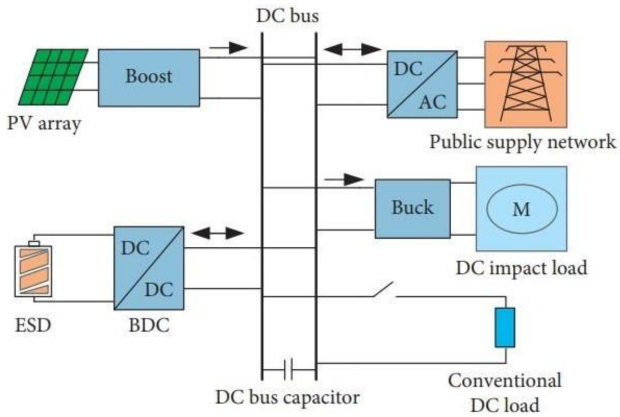

**Fig. 1** PV DC Microgrid Topology

- To overcome all above-mentioned problem, a FPDM controller is proposed in this paper, which make use of fuzzy controller for controlling the voltage of outer ring so as to give good performance during transient condition when voltage deviation becomes sufficiently large and make use of PI controller to achieve good steady state, when voltage deviation is small.

Further, a case study has been conducted for carrying out the experiments and it is found out that, the proposed FPDM controller has low overshoot, good response time, low transient and can be implemented in practical environment. The proposed paper is carved out as Section II that deals with Photovoltaic DC microgrid system, Section III will deal with FPDM controller, Section IV will deal with experiment result followed by conclusion.

Primary circuit architecture of PV DC Microgrid for off-grid operation is shown by Fig. 2.

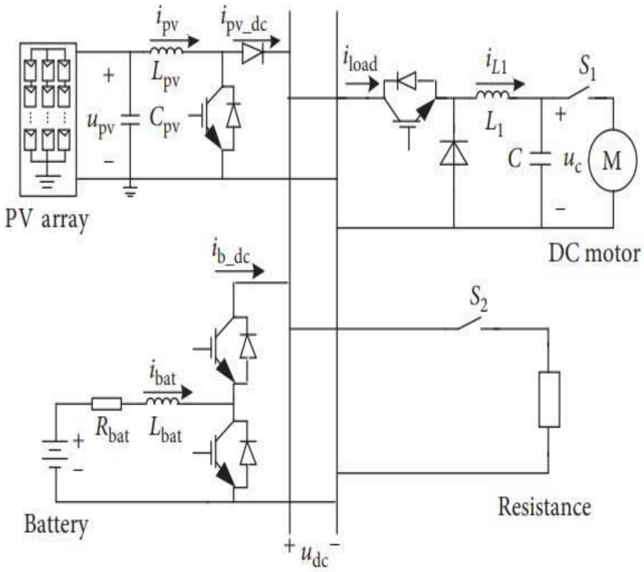

**Fig. 2** PV DC Microgrid Topology

From figure, dynamic equation of DC bus is given as Eq (1)

$$C_{dc}\frac{du_{dc}}{dt} = i_{pv\_dc} - i_{load} - i_{R}. \quad (1)$$

## 2. PVDCM SYSTEM

The block diagram of PVDCM system is shown by Fig.1 which consist of PV array, converter, batteries, load etc. Since DC microgrid has the capability to operate either in off grid mode or in grid connected mode, thus our aims is on to bus voltage stabilisation when DC microgrid operates in off-grid mode.

Where, LPV = Inductance of Boost Converter,

Lbat = Inductance of bidirectional converter L1 =

Inductance of buck converter

ipv_dc = Output current of boost converter iload =

Current of the Buck converter

iR = current through battery if modules are not considered

From eq (1) it is cleared that for controlling dc bus voltage there is requirement of PV modules and load current

According to equation (1), for controlling DC bus voltage there is a need of PV modules output and load current. Voltage of the DC bus is affected mostly by irregularities the photovoltaic output and the dynamic change of the load. As a result, it is impossible to ensure that the output current of the Boost converters is identical to the input current of the load throughout all periods whose equation (2) for the DC bus is

$$C_{dc}\frac{du_{dc}}{dt} = i_{pv\_dc} \pm i_{b\_dc} - i_{load} - i_{R} \quad (2)$$

When ib_dc is expressed as a positive value, it indicates that the battery is discharging and delivering energy to the system. When ib_dc is expressed as a negative value, it indicates that the battery is charging and absorbing the system's excess energy. The system is assured to operate safely and reliably by managing the charge and discharge of the battery to limit DC bus voltage fluctuation.

## 3. FPDM Controller

FPDM controller used here replaces the outer ring voltage by making use of both Fuzzy and PI controller in dual mode condition. For large deviation, fuzzy controller is used and when deviation is small, we can make use of PI controller to improve the range of mediation and steady state response respectively. A block diagram of FPDM controller is shown by Figure 3.

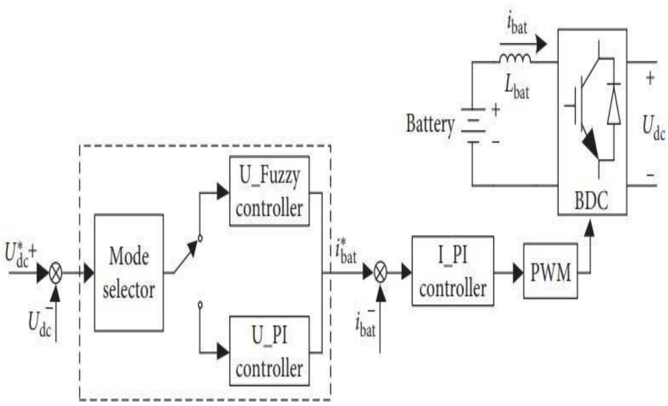


**Fig. 3** FPDM ControllerHere, Udc = Outer ring

Voltage
Ibat = Inner ring Current

## 4. Experimental Results

The parameters that are being used for conducting the experimental studies are shown by table 1**.**

| Parameters | Numerical Values |
|---|---|
| Output voltage of PV (V) | 12 |
| DC Bus Capacitance (uF) | 1000 |
| Rated Voltage (V) | 12 |
| Rated Capacity (Ah) | 38 |
| DC Motor power (W) | 30 |
| DC motor voltage (V) | 24 |
| DC motor current (A) | 2.1 |

**Table 1** Experimental Parameters

This experiment makes use of outer ring voltage for investigating three transient processes via PI control, fuzzy control and FPDM controller which is shown by Fig.4

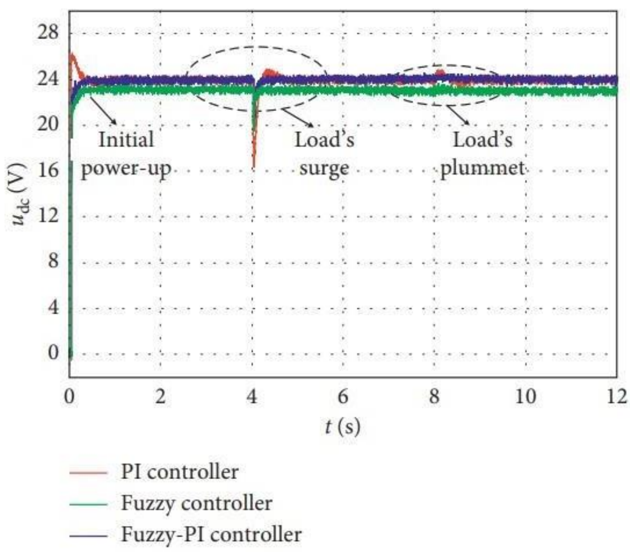


**Fig. 4** Transient Investigation

From Fig. 5, 6 & 7 it is clear that when fuzzy controller alone is used to handle these three transient conditions, outer ring voltage shows steady state errors and whereas with PI controller, there is more overshoot and poor dynamic performance. Whereas, with the use of FPDM controller improves dynamic response and reduces steady state fault.

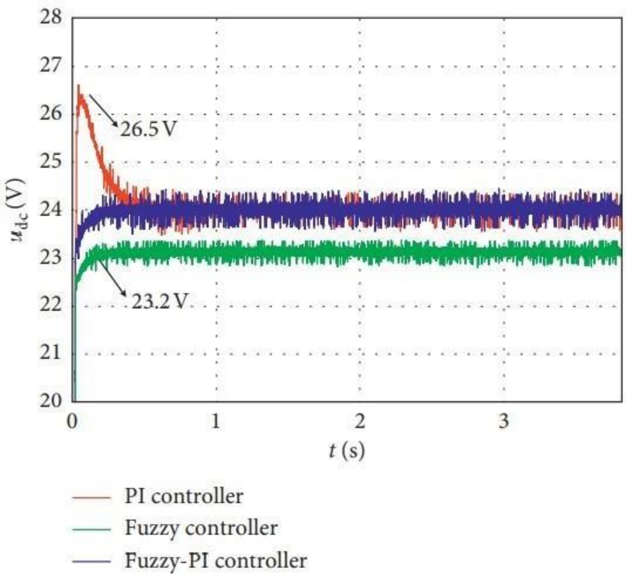


**Fig.5** Initial power Investigation with FPDM Controller

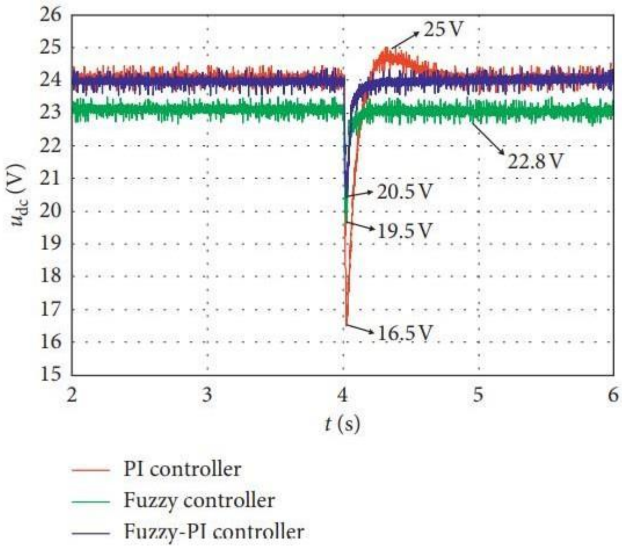


**Fig.6** Load's Investigation via FPDM Controller

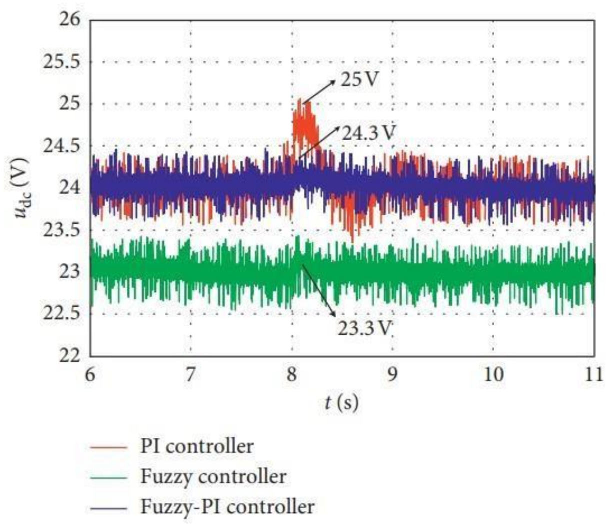


**Fig.7** Load's plummet Investigation via FPDM Controller

**Table 2** Comparison among different controlling strategies

| S.No | Different parameters | PI Controller | Fuzzy Controller | FPDM Controller |
|---|---|---|---|---|
| Initial Power Investigation | Adjustment time (s) | 0.4 | 0.2 | 0.2 |
| | Voltage Overshoot (V) | 2.5 | 0 | 0 |
| | Steady-State error(V) | 0 | 0.8 | 0 |
| Load's investigation | Adjustment time (s) | 0.2 | 0.2 | 0.2 |
| | Voltage Overshoot (V) | 7.5 | 4.5 | 3.5 |
| | Steady-State error(V) | 0 | 1.2 | 0 |
| Load's plummet investigation | Adjustment time (s) | 0.8 | 0.2 | 0.2 |
| | Voltage Overshoot (V) | 1 | 0.5 | 0.3 |
| | Steady-State error(V) | 0 | 0.8 | 0 |

## 5. Conclusion

This paper make use of FPDM controller is being proposed which make use of Fuzzy and PI dual model strategy. Whenever, DC bus voltage deviation is being large, this controller automatically switches to fuzzy mode for improving good transient condition and when bus voltage deviation is small, FPDM controller switches to PI mode for obtaining good steady state performance.

Further, compared to conventional controller, FPDM controller increase the robustness of the system by enhancing the dynamic response of the system and also it limits the DC voltage fluctuation level of the bus.

A comparison has been done through experiment validation which shows the adoptability of FPDM controller in practical environment.

**Author Contributions**: A.A.: Conceptualization, methodology, formal analysis, writing—original draft, B.B.; supervision, resources, project administration, C.C.; writing—review and editing, project administration, validation, DD.; writing—review and editing, project administration, validation. All authors have read and agreed to the published version of the manuscript.

**Funding:** The author(s) received no financial support for the research, authorship, and/or publication of this article.

**Conflicts of Interest:** The authors declare no conflict of interest.

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