ENHANCEMENT OF STABILITY OF DC MICROGRID CONTAINING CPL USING TYPE-2 FUZZY CONTROLLER AND MPPT CONTROLLER

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ABSTRACT

A microgrid is an efficient way to interconnect distributed energy resources. It is capable of providing sufficient and continuous energy to meet the load demand. The negative impedance characteristic of the constant power load (CPL) causes instability in DC/DC converters in the DC microgrids. To improve the stability of the DC/DC converter feeding CPLs, a robust and fast controller is required. In this paper a robust pulse-width modulation- based type-II fuzzy controller for a DC/DC boost converter connected to CPL in a DC microgrid was proposed and a MPPT controller to deliver maximum power to the CPL in a DC microgrid was designed.

Keywords: Constant power load (CPL), Type II fuzzy controller, DC/DC Converter

I. INTRODUCTION

The DC micro-grid circuit utilizes the constant power load and DC generator module. Both it is DC micro grid integrates with the various controlling techniques like PID and Fuzzy types. DC-micro grid is able to work in grid connected mode or islanded mode. When working in grid connected mode, the microgrid can either absorb power from the grid, or supply power to the grid depending on the amount of power it consumes and produces. If the microgrid generates more power than it needs, it can supply power to the grid. If the microgrid demands more power than it produces, it can absorb power from the grid. In islanded mode, the local energy sources need to supply all the local loads. A PID controller continuously calculates an error value as the difference between a desired output (reference) and a measured output and applies a correction based on proportional, integral, and derivative terms. Although a PID controller has three control terms, some applications use only one or two terms to provide the appropriate control. This is achieved by setting the unused parameters to zero and is called a PI, PD, P or I controller in the absence of the other control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value. The distinguishing feature of the PID controller is the ability to use. The fuzzy logic controller designed has two inputs and one output. The two inputs used for controlling the step down converter are the output voltage error and the change of error also known as the derivative of the error. The input membership functions in number of 5 are isosceles triangles. The inference system is of Mamdani type and the output is defined as singleton. The control output after de-fuzzyfication represents the duty cycle of the step down converter and based on its value the switch transfers the energy from the input of the converter to the output. The output voltage error is calculated as the difference between the output reference voltage and the actual measured value sensed through a voltage divider. Rapid developments in power distribution systems and renewable energy have widened the applications of dc – dc buck– boost converters in dc voltage regulation. Applications include vehicular power systems, renewable energy sources that generate power at a low voltage, and dc micro-grids. It is noted that the cascade–connection of converters in these applications may cause instability due to the fact that converters acting as loads have a constant power load (CPL) behaviour.

II. RELATED WORK

Aqulin Ouseph, et. al (2017) has presented the PID-Fuzzy logic based hybrid controlling technique. Here the Buck converter with DC signal generator is used by controlling of PID Fuzzy logic controller. To illustrate the effect of each controller type on the converter performance, the buck regulator topology is selected. Comparison between conventional PID controller, fuzzy logic controller and fuzzy PID hybrid controller, are presented. The comparison of result obtained from PID controller, fuzzy logic controller, fuzzy - PID hybrid controller for DC/DC converter shows the benefit of the hybrid algorithm in terms of transient response under load variation conditions.

Hamed F, et. al. (2020) has presented the design model of PID Fuzzy controller on DC Micro-grid. Feeding of constant power load of DC-DC converter circuit is interface with the PV and it regulates the switching pulse by PID-Fuzzy Type controller. To improve the stability of the DC/DC converter feeding CPLs, a robust and fast controller is required. This paper presents a robust pulse-width modulation based type-II fuzzy controller for a DC/DC boost converter feeding the CPL in a DC micro-grid.

G Vinothkumar (2018) has proposed the Fuzzy-PID control of hybrid system with wind energy generation. The hybrid converters are provides the energy to the load with better efficiency. The method of supplying the energy to the both loads such as AC load and DC load are done by using multi converters. More than one converter is used for AC and DC outputs in applications of micro grid as well as nano grid. Therefore the components are increased due to the utilization of more converters. This HDBC is supply the simultaneous DC and AC loads and the input power is obtained from the wind energy system. The system circuit consists of a power switch of the boost converter with single switch and the single phase inverter.

III.SYSTEM IMPLEMENTATION

A) PROPOSED SYSTEM

Block diagram of the Enhancement of stability of DC microgrid containing CPL using Type-2 fuzzy controller and MPPT controller is shown in Fig. 3.1 This system includes the fuel cell model, solar model, battery model and DC/DC converter, MPPT controller and CPL load. A boost converter is chosen for its simplicity and high efficiency as well as step up the load voltage. The solar and fuel cell act as the dc source for the converter, as well as the input for MPPT. The MPPT functioning to control the duty cycle of the converter, so that the maximum output power from the solar and fuel cell can be obtained.

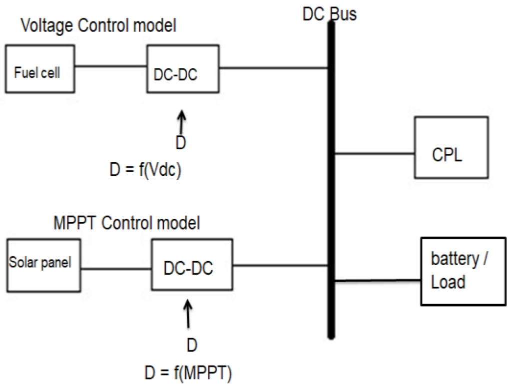

Fig: 3.1 Proposed block Diagram

B) MODELLING OF SOLAR PV (SPV) MODULE

For modeling, various techniques are available, but in this work, for simplicity, a single diode model is taken and shown in Fig. 3.2.

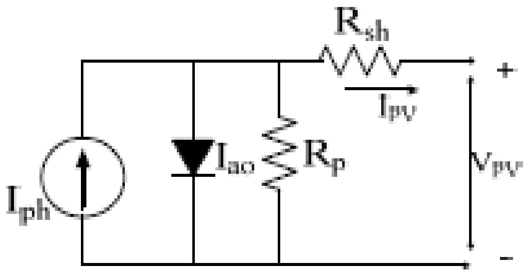

Fig. 3.2 PV Array Configuration

The mathematical formulation of the output current (I_{pv}) of the PV module is described as

$$I_{pv} = I_{ph} - I_{ao}\left[e^{\left(\frac{(V_{pv}+R_{sh}.I_{pv})\times q}{N_{cs}kT_c a_{fd}}\right)} - 1\right] - \frac{V_{pv}+R_{sh}I_{pv}}{R_p} \_\_\_\_\_ (1)$$

Where, I_{ph} is the photovoltaic current. I_{ao} is cell reverse saturation current or diode leakage current. V_{pv} are the module output voltage. R_{sh}(0.221Ω) and R_p(415.5Ω) are equivalent series and parallel resistance, N_{cs} is the number of series cells,q is the charge (of an electron) [1.60217646×10-19 C], the Boltzmann constant is k [1.3806503×10-23J/K], temperature of the cell's is T_c, α_{fd} is ideality factor of the diode (in general its value is 1≤α≤1.5).

The mathematical details of I_{ph} and I_{ao} are described as,

$$I_{ph} = \left(\frac{R_P+R_{sh}}{R_P} I_{sc} + K_i(T_c - T_{ref})\right)\frac{S}{S_{ref}} \_\_\_\_\_ (2)$$

$$I_{ao} = \frac{I_{sc}+K_i(T_c-T_{ref})}{e^{\left(\frac{V_{oc}+K_v(T_c-T_{ref})}{N_{cs}\,kT_c\,a_{fd}}\times q\right)} - 1} \_\_\_\_\_ (3)$$

Where, I_{sc} and V_{oc} are short circuit current and open circuit voltage, K_i and K_v are coefficient of current (0.0032A/K) and voltage (-0.123V/K), T_c and T_{ref} are cell's working and reference temperature (25℃), S and S_{ref} are the working and reference irradiation (1000W/m2).

C) ENERGY STORAGE

Battery is a storage device which stores the excess power generated and uses it to supply the load in addition to the generators when power is required. The PV energy system (described in the previous chapters) is integrated i.e. connected to a common DC bus of constant voltage and the battery bank is also connected to the DC bus via a bidirectional converter. Any power transfer whether from PV array to battery bank or PV array to load or from battery bank to load or from load to load takes place via bidirectional converter. As the power flow associated with the battery is not uni-directional, a bidirectional converter is needed to charge and/or discharge the battery in case of excess and/or deficit of power respectively. Since batteries are dynamic in nature, the charging/discharging processes of battery reduces its lifespan. In PV systems, with the view to increase the lifespan of the battery, a battery energy storage system requires a battery energy management system. The objective of the energy management system is to maximize the power coming from the PV panel, minimize grid power, and minimize the charging and discharging of the battery and protect the battery from overcharging and discharging. It should also coordinate the power flow when the system is grid connected.

D) CONSTANT POWER LOAD UTILITY

The output voltage of renewable energy sources is defined as E and the total load is considered to be a CPL, which represents a worst-case scenario from the stability point of view. Moreover, it is assumed that the DC/DC boost converter operates in the conduction mode (CCM). The DC/DC boost converter is responsible for the regulation and stabilization of the DC bus voltage as well as for supplying the demanded constant power of the CPL. The switching frequency of the Pulse Width Modulator (PWM) D is the duty cycle taking values in the interval [0,1]. However, when such a converter is part of a DC micro grid a totally different type of loading is possible, i.e so-called Constant Power Load.

E) MODELLING OF FUEL CELL

PEM fuel cell electrochemical process starts on the anode side (Fig 1.) where H_2 molecules are brought by flow plate channels. Anode catalyst divides hydrogen on protons H^+ that travel to cathode through membrane and electrons e^- that travel to cathode over external electrical circuit. At the cathode hydrogen protons H^+ and electrons e^- combine with oxygen O_2 by use of catalyst, to form water H_2O and heat. Described reactions can be expressed using equations:

$$H_2 \rightarrow 2H^+ + 2e^- \text{ (Anode)},$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_20 \text{ (Cathode)}.$$

Amount of chemical energy released in these reactions depends on hydrogen pressure, oxygen pressure and fuel cell temperature. Using change in Gibbs free energy, this amount can be expressed as:

$$\Delta g_f = \Delta g_f^0 - RT_{fc}\left[\ln(p_{H2}) + \frac{1}{2}\ln(p_{O2})\right],$$

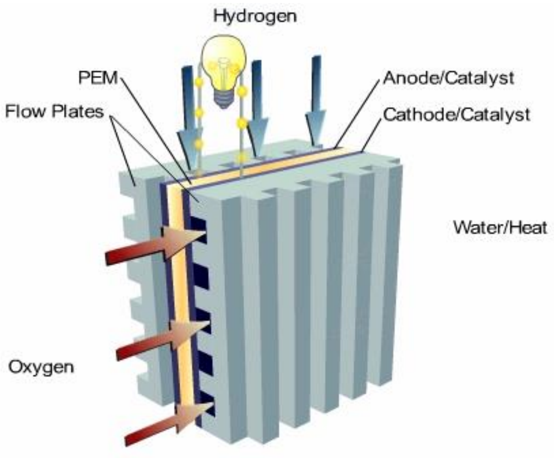

Fig: 3.2 Fuel Cell

F) PERTURB AND OBSERVE (P&O) MPPT

The most commonly used MPPT algorithm is P&O method. This algorithm uses simple feedback arrangement and little measured parameters. In this approach, the module voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous perturbing cycle. In this algorithm a slight perturbation is introduce to the system. This perturbation causes the power of the solar module various. If the power increases due to the perturbation then the perturbation is continued in the same direction. After the peak power is reached the power at the MPP is zero and next instant decreases and hence after that the perturbation reverses.

When the stable condition is arrived the algorithm oscillates around the peak power point. In order to maintain the power variation small the perturbation size remain very small. The technique is advanced in such a style that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller then acts to transfer the operating point of the module to that particular voltage level. It is observed some power loss due to this perturbation also the fails to track the maximum power under fast changing atmospheric conditions. But remain this technique is very popular and simple.

i) P&O MPPT algorithm

The problem considered by MPPT methods is to automatically find the voltage VMPP or current IMPP at which a PV array delivers maximum power under a given temperature and irradiance. In P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV Array current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. The duty cycle of the dc chopper is varied and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. For different values of irradiance and cell temperatures, the PV array would exhibit different characteristic curves. Each curve has its maximum power point. It is at this point, where the corresponding maximum voltage is supplied to the converter.

ii) P&O MPPT FLOW CHART

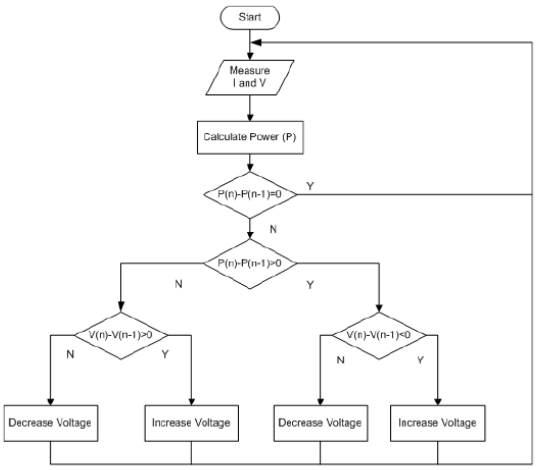

Fig: 3.3 P&O Flow Chart

G) TYPE 2 FUZZY LOGIC

A T2FL controller is proposed for the control of the buck and boost DC–DC converters to achieve a good output voltage regulation and dynamic response against. Similar to type-1 fuzzy logic systems, type-2 fuzzy logic systems comprise fuzzifier, rule base, inference engine and output processor. One of the most important differences between type-1 fuzzy logic and type-2 fuzzy logic systems takes place in the output processing. The output processing of type-2 fuzzy logic systems includes type reducer which converts the type-2 fuzzy out- put sets into type-1 sets and defuzzifier which maps type-1 fuzzy sets obtained from type reducer into crisp data. There- fore, the type reduction captures more information about rule uncertainties than that of a crisp number. Another important difference between these systems is the membership sets used in the fuzzifier. A type-2 fuzzy set is characterized by a fuzzy membership function, i.e., the membership value (or membership grade) for each element of this set is a fuzzy number in [0,1]. Thus, these sets can be used in situations where there is uncertainty about the membership grades themselves, e.g., an uncertainty in the shape of the membership function or in some of its parameters.

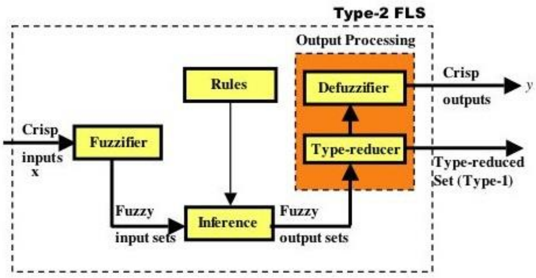

Fig: 3.4 Type-2 Fuzzy tool box

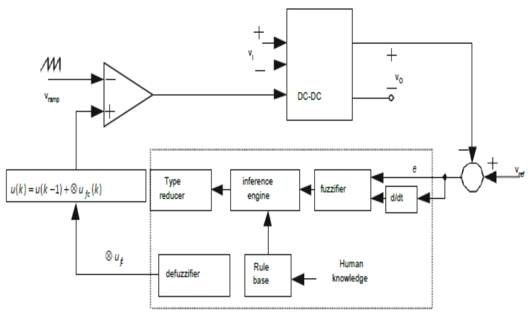

Fig: 3.5 Block diagram of type-2 fuzzy logic controller used for control of DC-DC converter

IV-RESULTS AND DISCUSSION

The proposed work is completed on MATLAB software on the version of 2020a. The designed circuits were drawn and simulated using MATLAB Simulink and Sim power system toolboxes.

A) SIMULINK MODELS

The figure 4.1 and 4.2 depicts the PV model that is designed in MATLAB Simulink platform and solar array respectively.

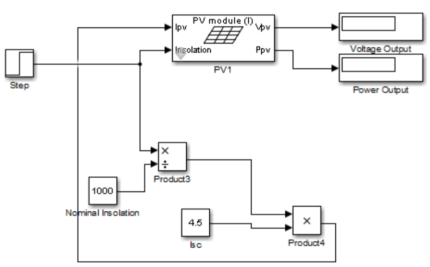

Fig: 4.1 PV Model

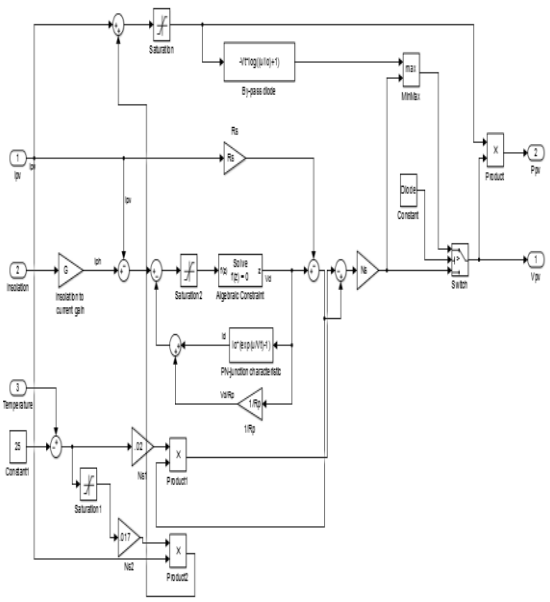

Fig: 4.2 PV model

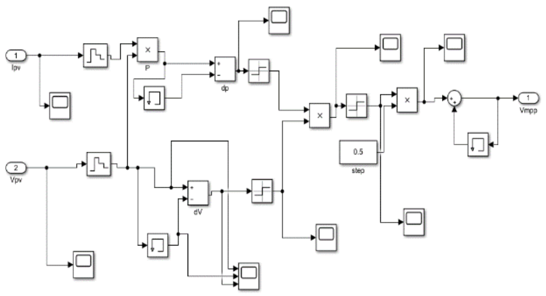

Fig: 4.3 MPPT Model

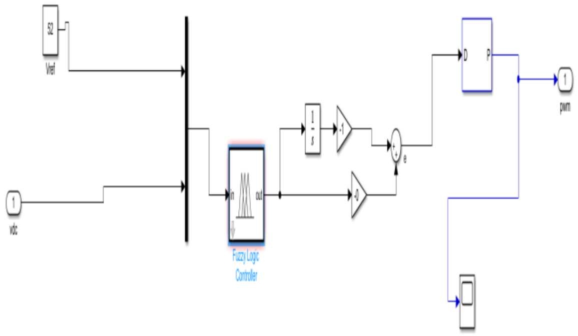

Fig: 4.4 Type-2 Fuzzy Model

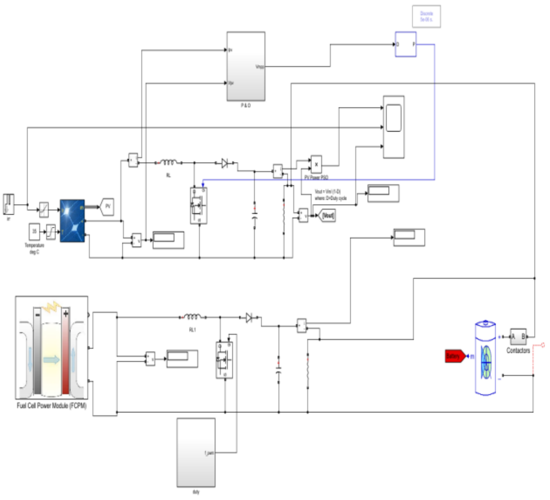

Fig: 4.5 Proposed Simulink topology

The designed Enhancement of stability of DC microgrid containing CPL using Type-2 fuzzy controller and MPPT controller topology is represented in the following figure 4.5

B) Similation Result

The below figure 4.5 is output for MPPT controller.

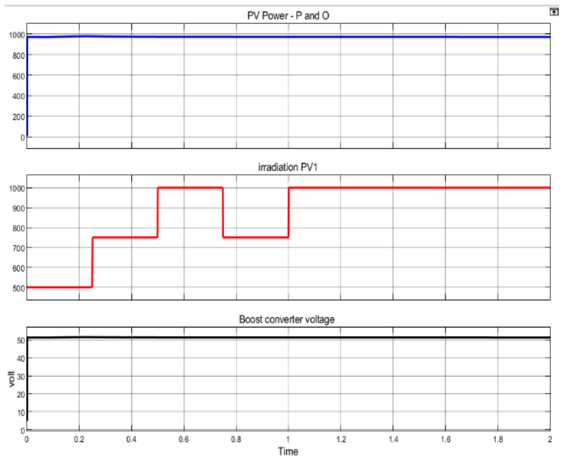

Fig: 4.5 MPPT Output

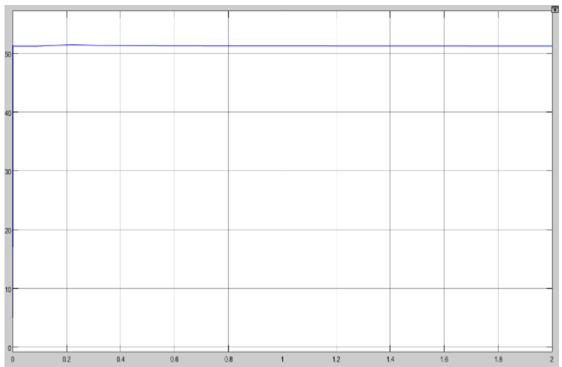

Fig: 4.6 Output for DC/DC Converter

The above figure 4.6 is output voltage of DC/DC converter the voltage of converter is 52V DC.

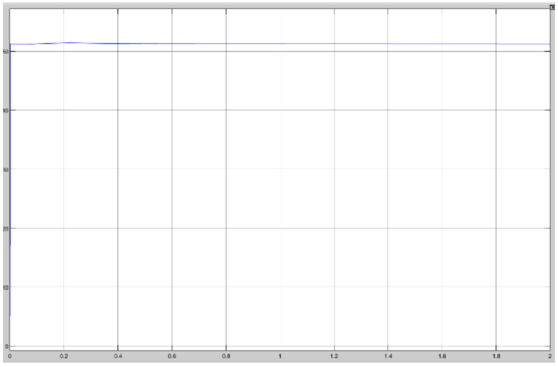

Fig: 4.7 Output for DC Bus

The above figure 4.7 is shown as output of DC bus side and the CPL load side voltage of constant power of 48V 300Watts

C) Table of Input and Output Voltage

Table 4.1 Specification of Model

Components	Voltage(V)	Power(Watts)
Solar	30V-50V	250Watts
Fuel Cell	40V	200Watts
Battery	48V	40Ah
CPL Load	48V	300Watts

Table 4.2 Input & Output voltage

Source	Input	DC/DC Output
solar	30-50V 250watts	52Volt
Fuel Cell	40V 200watts	52Volt

V. CONCLUSION

In this project, a hybrid DC microgrid with various control techniques has been proposed to achieve maximum power point in solar PV and FC. The MPPT method improves the settling time of the proposed hybrid DC microgrid, according to the results obtained using different control techniques such as Type-2 FLC, and PSO algorithm. When other control methods, Type-2 FLC has a higher efficiency rating. The results shows that the type -2 fuzzy MPPT approach for forecasting hybrid DC microgrid output has a high level of precision, effectiveness, and reliability. This research has been applied to both grid and stand-alone systems. As a result of this research into different control techniques for MPPT systems, it is now possible to choose a particular MPPT process for various applications. We will investigate the possibility of implementing the appropriate control methods to other types of DC-DC converters as well as to control a DC microgrid with advanced DC-DC converter topologies in future research.

REFERENCES

[1] Hamed Farsizadeh, Meysam G, Mahdi M, Mehdi R and Mohammad Hassan Khooban, “An intelligent and fast controller for DC/DC converter feeding CPL in a DC Microgrid,” IEEE Transactions on circuits and systems II: Express Briefs, pp. 2019. DOI 10.1109/TCSII.2019.2928814

[2] Mohammad Sarvi, Nafiseh Namazy Pour, “A new PID-Fuzzy controller for DC/DC converters,” 43rd International Univ. Power Engg. Conf., 1-4 Sept. 2008, Padova, Italy. IEEE 2008.

[3] Mohammed Kh AL-Nussairi, Ramazan B, Sanjeevikumar P, Lucian Mihet-popa and Pierluigi S, “Constant power loads (CPL) with Microgrids: Problem Definition, stability analysis and compensation techniques, Energies, 10(10): 1656, 2017. https://doi.org/10.3390/en10101656.

[4] Mohammed AL-Nussairi and R Bayindir, “DC-DC Boost converter stability with constant power load,”18th International power electronics and motion control conference, Aug. 2018. DOI: 10.1109/EPEPEMC.2018.8521757

[5] Rivetta C, G A Williamson, “Global behavior analysis of a DC-DC boost power converter operating with constant power load,” IEEE International symposium on circuits and systems, 23-26 May 2004, Canada.

[6] VC Kotak and Preti Tyagi, “DC to DC Converter in maximum power point tracker,” International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering, 2(12): 6115-6125, Dec. 2013.

[7] Carlos Abraham, Wei He, Fernando M David and Romeo Ortega, “Voltage regulation in buck-boost coninverters feeding an unknown constant power load: an adaptive passivity based control,” IEEE Transactions on control systems and technology, pp. 1-8, 2020.

[8] Jiwei Sun, Wei Lin, Mingguo Hong and Kenneth A Loparo, “Voltage regulation of DC Microgrid with PV and battery: A passivity method,” IFAC-Projects on line, 52(16): 753-758, 2019. https://doi.org/10.1016/j.ifacol.2019.12.053

[9] Vimala V, Venkat Reddy, “PID-Fuzzy logic hybrid controller for a digitally controlled DC-DC converter,” International conference on green computing, communication and conservation on energy, 12-14 Dec. 2013, Chennai, India. https://doi.org/10.1109/ICGCE.2013.6823461

