Performance Analysis of Power Electronic Distribution Transformer using Adaptive Pi-Fuzzy Logic Controller

Vishnupriya K., Ramya G.

Abstract: ***This paper enlightens the analysis of distributed transformer using novel controller. The transformer initiates power distribution by stepping up or down depends upon the need. In accordance with power quality issues, performance, dynamic response, power factor correction the normalized transformer is inconvenient. Replacing the uncertainties by introducing a power electronic distribution transformer (PET) with PI controlled adaptive fuzzy logic control (APIFC). Moreover the occurrence of breakdown voltage and stress in conventional method, this method becoming more popular. This transformer become sensitive to dealt with swell, sag, voltage regulation, open circuit and short circuit fault. The specified rectifier also does power factor correction. The strategic PI controller with adaptive fuzzy logic control technique is established to respond sudden change or variation occurs in load. The fuzzy logic controller (FLC) posses five set of rules and PI controller adapt with one among five set of rules. This makes the controller to adjust with variation and improves power quality. The simulation is carried out using MatLab-Simulink.***

Keywords: Power Electronic distribution transformer (PET), Proportional Integral control (PI), Fuzzy Logic controller (FLC), Adaptive fuzzy proportional integral control (APIFC)

I. INTRODUCTION

The power transformer has sustainable for power distribution system. The conventional transformer becoming huge in size, suffers from harmonics, internal core losses, etc. Normally a transformer undergoes hysteresis loss, eddy current loss and dielectric loss [1]-[5]. When non-linear load is attached with conventional transformer, it undertakes severe heat and losses in transformer winding. So it could not have high power control capacity. As from the above record it is visualized that the usual transformer is not well suited for distribution system. The power electronic distribution transformer has been considered as a solution for distribution system. It promotes long transmission with unity power factor and power correction. The emerging technology is responsible for rectifying losses occurs within the system. It relives system from dielectric loss, voltage fluctuation, and harmonic distortion. Moreover that, this system imparts huge power transmission without any difficulties (i.e.) sag, swell, open circuit and short circuit fault. Normally a power electronic distribution transformer posses power semiconducting devices at both front end and back end respectively. The PET employs two strategies: 1) without DC Link capacitor, 2) with DC link capacitor. The power distribution system cannot have dc link capacitor; so the construction becomes simple, less weight, less stress factor [6]-[8]. But this type does not contribute towards power conversion and power improvement. In second approach the DC link can have the ability to perform power factor correction and voltage regulation. This method has becoming more convenient for voltage regulation. In our proposed system the dc link capacitor included. The size of the transformer become compact, more efficient, draws attention immediately when disturbance occurs. The fuzzy logic associated with PI controller has been included with PET to obtain better performance. The adaptive fuzzy logic controller contains five rules [9]-[12]. The PI control technique would not have the ability to acts upon the changes and variation in voltage. Hence the quality of power may fail. Then we introduce fuzzy logic control with PI to accept the changes occur in a system; also provide a better solution to the system. The proposed topology is further divided into three sections namely: input stage, isolation stage, output stage shown in Fig.1 In input stage the three phase supply is converter into dc supply. In output stage three phase present within it. It converts the dc into ac voltage efficiently. More or less from the previous sections are corrected in this section. Finally the required output is fed to the load without any fault. Further power factor correction and power regulation is also possible in this proposed topology. Apart from control technique, these topology posses a unique solution for power factor correction. Most of the rectifiers perform rectification only. But this can acts as power factor correct ion converter also. The Vienna rectifier brings power from the AC supply. It transforms ac into dc voltage and capacitor present in it can perform power factor correction.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.
* Correspondence Author
Vishnupriya K., UG Student, Department of Electrical and Electronics Engineering, Saveetha School of Engineering, Chennai, India.
E-mail: manikanta9118@gmail.com
Ramya G., Assistant Professor, Department of Electrical and Electronics Engineering, Saveetha School of Engineering, Chennai, India.
E-mail: ramyag.sse@saveetha.com

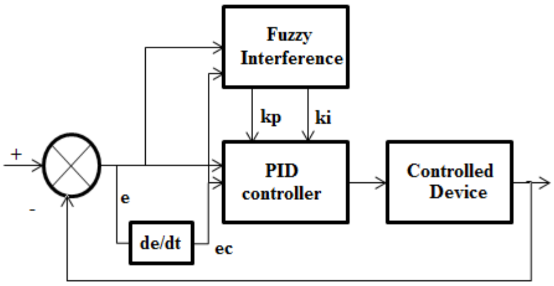


Fig.1. Schematic block of proposed system

Therefore the output power has low ripple and it is at acceptable rate. It does not create harness to the converter portion. If there is any disturbance within input voltage the rectifier corrects and do not make trouble in converter portion. A multi-fed power electronic transformer has the ability to function with active power from the feeder and performs lossless power improvement with ac-dc and dc-ac conversion topology. It enrols flexibility and smart grid concept. These topology also governs power quality is represented. The protection of transformer under various circumstances like low frequency disturbance, grounding and over voltage is proposed. It is essential to provide grounding when the transformer faces low frequency during transmission. The medium voltage stress generated arc suspension coil is caught and negative sequence current compensation is chosen as remedy to this problem. By injecting zero sequence voltage, the arc suspension impedance also adjusted. Hybrid AC-DC conversion with multiple voltage level evolves cascaded multiport power electronic transformer enable reliability and redundancy. Both AC/DC conversion and power electronic transformer reliability and redundancy are analysed under various operating conditions. In paper, medium and high voltage applications, smart grid power distribution employ dc power electronic distribution transformer. To locate the faulty section quickly and respond well with fewer switches and high frequency transformer without any change in line voltage; does not require any impedance injection. The solid state transformer (power electronic transformer) interfaced ac and dc distribution grid using dual active bridge converter, high frequency transformer, and multilevel cascaded ac/dc rectifier is conveyed. This topology makes correction upon unbalanced dc link voltage and semiconductor stress causing over voltage or over current. A single phase dq model, rectifier and real power flowing through dual active bridge converter are also established [13]-[17]. The adaptive fuzzy inter combined with PI control accepts the variation in load, ac grid, variable operating conditions is proposed. Instead of dc link capacitor a high frequency ac link capacitor adjust with variable frequency and pulse width modulation (PWM) from a source. At output stage the leakage energy from isolation stage is recovered. This deals with the quality and controllability using high frequency transformer, centralized ac-dc converter, high frequency transformer using less switches. A fuzzy logic control based solid state transformer ignore fault within system load line and it takes action upon variable operation of converter with respond to input voltage. Rectifier performs power factor correction; also discrete space vector modulation controls rotational motion of motor, ripple, noise.

II. PROPOSED SYSTEM

The schematic circuit of proposed system is shown in Fig.2. The proposed system has three categories: an input, isolation and output stage. The input stage acts as rectifier circuit where ac in converted into dc signals. The first stage rectifier is used to improve the power factor and regulate the supply voltage. The second stage consists of two half bridge converter connected to high frequency transformer. In first half bridge the converter generated high frequency square wave voltage and then stepped down to dc voltage. The final stage is dc-ac inverter converter where the dc signals s converted to ac to feed the load. The mathematical modelling of abc frame of three level PWM rectifier is

$$e_a = L\frac{di_a}{dt} + Ri_a + s_{a1}v_{dc1} - s_{a2}v_{dc2} + u_{n0} \quad (1)$$

$$e_b = L\frac{di_b}{dt} + Ri_b + s_{b1}v_{dc1} - s_{b2}v_{dc2} + u_{n0} \quad (2)$$

$$e_c = L\frac{di_c}{dt} + Ri_c + s_{c1}v_{dc1} - s_{c2}v_{dc2} + u_{n0} \quad (3)$$

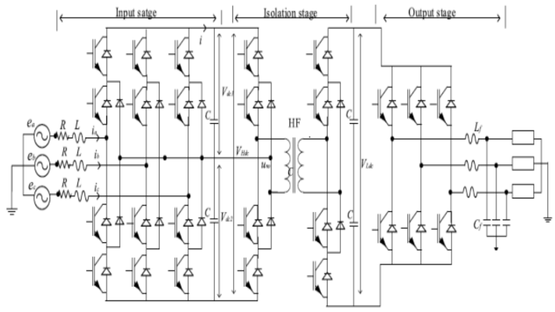


Fig.2. Proposed topology

The dc capacitor voltages are

$$C_d\frac{dv_{c1}}{dt} = s_{a1}i_a + s_{b1}i_b + s_{c2}i_c - i \quad (4)$$

$$C_d\frac{dv_{c2}}{dt} = -s_{a2}i_a - s_{b2}i_b + s_{c2}i_c - i \quad (5)$$

Where

e_a, e_b, e_c - ac input voltages

L - Inductance

R - Resistance

V_{dc1} and V_{dc2} - DC-link voltage,

iI - rectifier output current,

C_d - DC-link capacitor

S_a, S_b, and S_c - switching functions

u_{no} - voltage between the grid neutral point

Modelling and design of controller is implemented by converting abc variables into d-q frame. The rectifier circuit with synchronous rotation d-q coordinate can be represented as

$$L\frac{di_d}{dt} = -Ri_d + \omega Li_q - s_{d1}v_{dc} + s_{d2}v_{dc} + e_q \quad (6)$$

$$L\frac{di_q}{dt} = -Ri_q + \omega Li_d - s_{q1}v_{dc} + s_{q2}v_{dc} + e_q \quad (7)$$

The input stage PI controller is shown in Fig. 3. The closed loop control can be implemented at the input stage can be done with the above equations.

To regulate the output voltage the output voltage and reference voltage are compared to control. The compared output is given to PI controller which gives the reference signal to control inner current i_{dref} and i_{qref} to achieve unity power factor. Id and iq currents are compared with i_{ref} and the error signal is fed to PI controller. The reference current is multiplied with ωL to generate the reference voltage to the gate drive circuit.

The gating pulse for the converter is generated by comparing dc link voltage with reference voltage. The control gain values K_P and K_I are determined by Ziegler-Nichols tuning method. The K_P value is represented with ultimate gain constant Ku with time instant T_U.

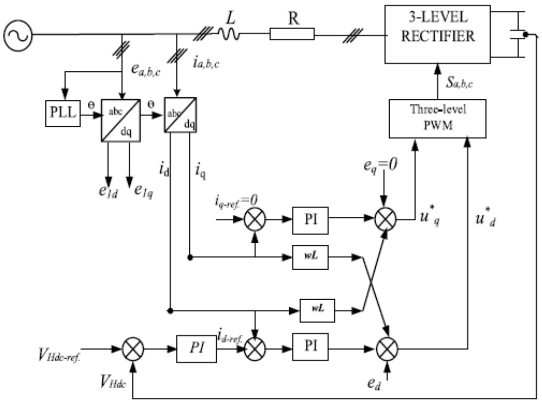


Fig.3. Block diagram of the input stage using the PI controller

These values are used to determine the PI controller parameters. The fixed gain values leads to dynamic performance of the system. To overcome this issue, the conventional PI controller was modified to give better dynamic performances by using adaptive fuzzy PI controller.

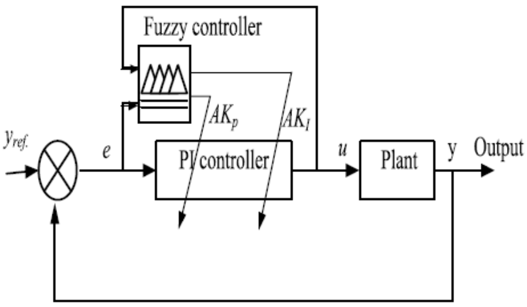


Fig.4 PI controller adapted with fuzzy controller.

The FLC automatically tunes the PI controller gain parameters such that it manages both linear and nonlinear operation. Fig.4. represent the structure of the proposed adaptive fuzzy PI control system. The proposed FLC controller consists of two inputs and two output signals. The two input signal are the error (e) and controller output signal (u). The output of the FLC block is the two gain values K_P and K_I. When the system is operating under the steady-state condition, the output is controlled by the PI controller gains. Under the dynamic condition the FLC automatically tunes the PI gains based on the error (e) signal and the change in the PI output control signal (u). The membership functions of FLC are shown in Fig. 5(a) & 5(b).

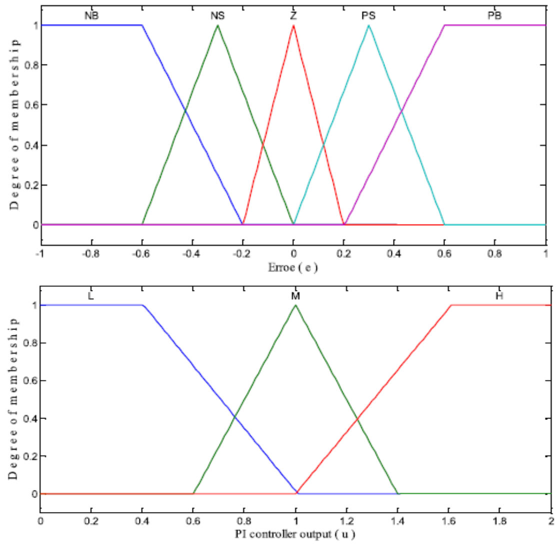


Fig.5(a) Inputs membership function for FLC

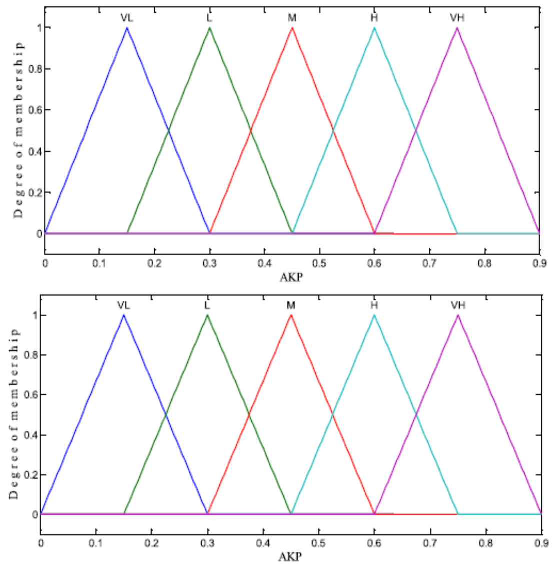


Fig.5(b) Output membership function

The fuzzy rules are framed for Kp and Ki as follows

Table I Fuzzy rules for K_p and K_I of Proposed system

u/e	NB	NS	Z	PS	PB
L	VH	H	M	L	M
M	H	M	L	L	H
H	M	L	VL	VL	H

u/e	NB	NS	Z	PS	PB
L	H	M	L	VL	VL
M	M	L	L	M	VL
H	M	VL	VL	H	M

The simulation parameters of the proposed system is given in Table II

Table II Simulation Parameters of Proposed system

Parameters	Value
S	100kVa
V_{in}	11kV

Retrieval Number: F8066038620/2020©BEIESP
DOI:10.35940/ijrte.F8066.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

V_0	0.415kV
L	0.25H
R	0.07Ω
C_{dc1}, C_{dc2} (high)	20μF
V_{hdc}	20kV
C_{dc1}, C_{dc2} (low)	30mF
V_{Ldc}	0.8kV
F_{sw}	10kHz
L_f	4mH
R_f	100kW

III. RESULT AND DISCUSSION

The simulation is carried out using MatLab platform. The performance analysis is carried based on voltage sag and harmonic distortion

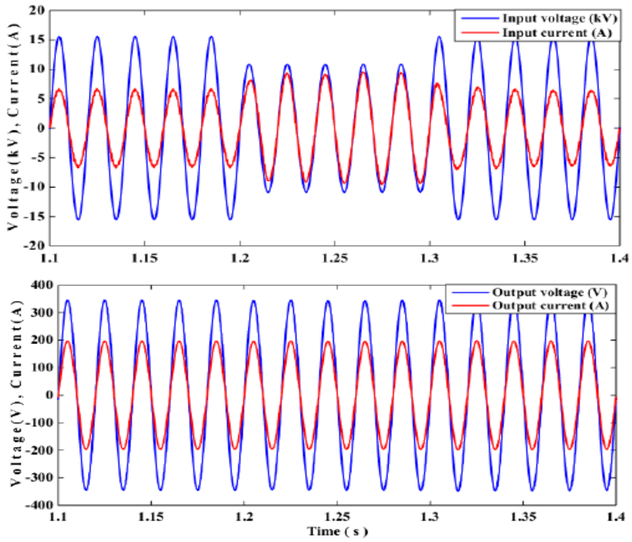


Fig.6. Input-output voltage and current response with API-FLC

A deviation at voltage is introduced at time instant 1.2 to 1.3 s as shown in Fig.6. Due to adaptive fuzzy PI controller unit the voltage deviation is compensated as shown in Fig. 6.

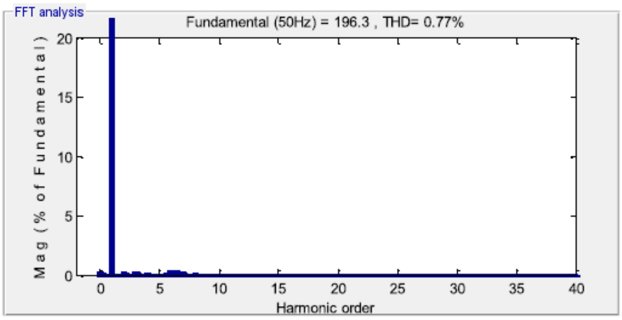


Fig.7. Output current THD with PI controller

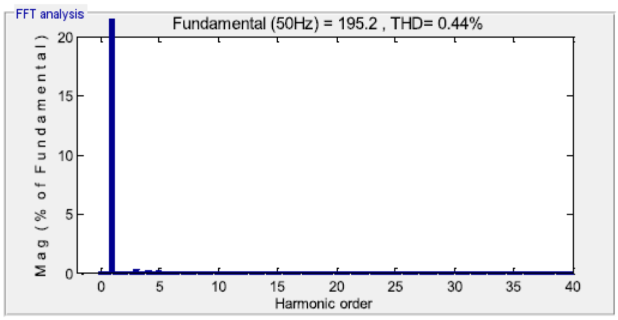


Fig.8. Output current THD with proposed controller

The THD for both the conventional PI and adaptive FLC controller are shown in Fig.7 & 8. The PI controller has an output current THD of 0.77% and adaptive FLC is 0.44% having lower harmonics and improved power quality.

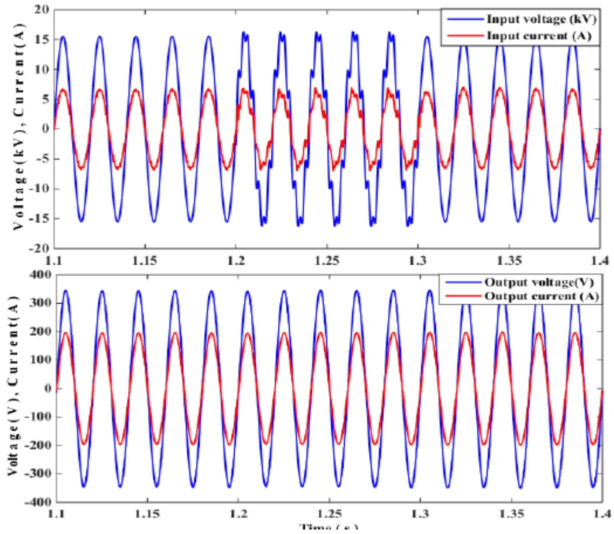
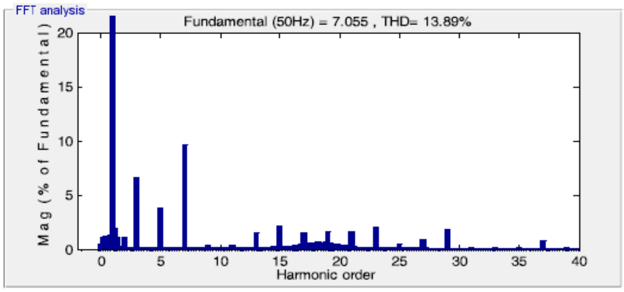


Fig.9. Input-output voltage and current response under voltage harmonics



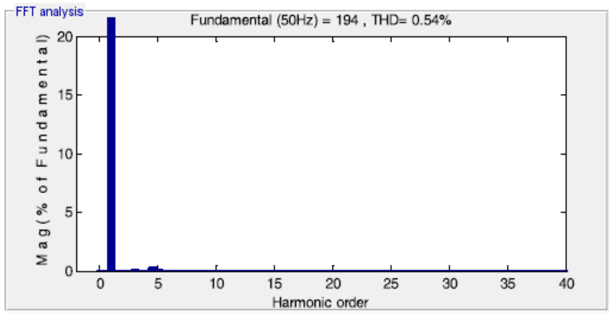


Fig.10. Output current THD with API-FLC

The voltage harmonics is applied at primary side of transformer having THD of 13.89% as shown in Fig. 9. And the transformer secondary output current THD of 0.54% is shown in Fig.10. The THD percentage satisfies the IEEE standard which is less than 5%. From the obtained simulation results it is inferred that the proposed system has improved power quality and less harmonics.

IV. CONCLUSION

In this research work a novel adaptive FLC based PI controller is implemented. The proposed controller unit automatically adjusts the gain value based on the deviation at the output side and the performance analysis is carried out based on harmonics and voltage compensation under dynamic condition.

Based the obtained simulation results the proposed controller has less harmonics and better performance under dynamic state compared to conventional PI controller.

REFERENCE

1. Juan M. Ramirez, Johnny Posada Contreras, "Multi-Fed Power Electronic Transformer for Use in Modern Distribution Systems", IEEE Transactions on Smart Grid , Vol. 5, No. 3, 2014.
2. Shaodi Ouyang ; Jinjun Liu ; YueYang ; Xingxing Chen, Shuguang Song , Hongda Wu, "Control Strategy for Arc-Suppression-Coil-Grounded Star-Connected Power Electronic Transformers", IEEE Transactions on Power Electronics , Vol. 34 , No. 6, 2019.
3. Haibo Li ; Zhanqing Yu ; Rong Zeng, Yi Liu, "Reliability evaluation method for AC/DC hybrid distribution power network considering cascaded multiport power electronic transformer", IET Generation, Transmission & Distribution, Vol. 13, No. 23, 2019.
4. Jingxi Yang, Nan Zhao, Yang Wang, Trillion Q. Zheng, Jiepin Zhang , Jianqiang Liu, "A Modified DC Power Electronic Transformer Based on Series Connection of Full-Bridge Converters", IEEE Transactions on Power Electronics, Vol. 34, No. 3, 2019.
5. T. Zhao, G. Wang, S. Bhattacharya, and A. Q. Huang, "Voltage and power balance control for a cascaded H-bridge converter-based solid state transformer", IEEE Transactions on Power Electronics, Vol. 28, pp. 1523-1532, 2013.
6. I. Sefa, N. Altin, S. Ozdemir, and O. Kaplan, "Fuzzy PI controlled inverter for grid interactive renewable energy systems," IET Renewable Power Generation, vol. 9, pp. 729-738, 2015.
7. K. Basu and N. Mohan, "A single-stage power electronic transformer for a three-phase PWM AC/AC drive with source-based commutation of leakage energy and common-mode voltage suppression", IEEE Transactions on Industrial Electronics, vol. 61, pp. 5881-5893, 2014
8. X. She, A. Q. Huang, and R. Burgos, "Review of solid-state transformer technologies and their application in power distribution systems", IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, pp. 186-198, 2013
9. H. Açıkgöz, Ö. F. Keçecioğlu, A. Gani, C. Yıldız, and M. Şekkeli, "Optimal Control and Analysis of Three Phase Electronic Power Transformers", Procedia-Social and Behavioral Sciences, vol. 195, pp. 2412-2420, 2015
10. June-Seok Lee, Kyo-Beum Lee, Frede Blaabjerg, "Predictive Control with Discrete Space-Vector Modulation of Vienna Rectifier for driving PMSG of Wind Turbine Systems" IEEE Transactions on Power Electronics, 2018 vol.26 DOI :10.1109/TPEL.2019.2905843,
11. Wenlong Ding, Chenghui Zhang, Feng Gao, Bin Duan, "A Zero-Sequence Component Injection Modulation Method with Compensation for Current Harmonic Mitigation of Vienna Rectifier" IEEE Transactions on Power Electronics 2018 vol.7, DOI: 10.1109/tpel.2018.2812810.
12. June-Seok Lee, Kyo-Beum Lee, Frede Blaabjerg , "Predictive Control with Discrete Space-Vector Modulation of Vienna Rectifier for driving PMSG of Wind Turbine Systems", IEEE vol.9,DOI: 10.1109/TIE.2014.2347912.
13. Damodhar Reddy, Sudha Ramasamy, "Design of RBFN Controller Based Boost Type Vienna Rectifier for Grid-Tied Wind Energy Conversion System" Volume 6, 2018 IEEE Access.Vol.7,DOI: 10.1109/ACCESS.2017.2787567.
14. Jaipal Saroha, Mukhtiar Singh, D. K. Jain, "ANFIS Based Add-on Controller for Unbalance Voltage Compensation in Low Voltage Micro grid", IEEE Transaction on Industrial Informatics vol.6, DOI:10.1109/TII.2018.2803748.
15. Ali R. Izadinia, Hamid R. Karshenas,"Current Shaping in a Hybrid 12-Pulse Rectifier Using a Vienna Rectifier" IEEE Transactions on Power Electronics Vol.5DOI:10.1109/TPEL.2017.2685459
16. Umair A. Shaikh, Mohammad K. AlGhamdi, Hussain A. AlZaher, "Novel product ANFIS-PID hybrid controller for buck converters", The Journal of Engineering .Vol.8,DOI: 10.1049/joe.2018.0113 .
17. Wenjie Zhu, Changsong Chen, ShanXu Duan, Tao Wang, Peng Liu, "A Carrier-based Discontinuous PWM Method with Varying Clamped Area for Vienna Rectifier", IEEE Transactions On Industrial Electronics vol.7,DOI : 10.1109/tie.2018.2873524.

AUTHORS PROFILE

K. Vishnu Priya pursuing her Under Graduate Degree in the Department of Electrical and Electronics Engineering at Saveetha School of Engineering, Chennai. Her areas of interests include Power Electronics

G. Ramya working as Assistant Professor in the Department of Electrical and Electronics Engineering at Saveetha School of Engineering, Chennai. She acquired her Bachelor's degree in Electronics and Communication Engineering from Anna University, Tiruchirapalli in 2011. She obtained her Master's degree in Power Electronics and Drives from Anna University, Chennai in 2013 and Ph.D degree from Anna University, Chennai. She has over 5 years of experience in teaching and guiding projects. Her areas of interests include Power Electronics, Renewable Energy Sources.