TYPE II FUZZY LOGIC BASED UNIT VOLTAGE TEMPLATE FOR IMPROVING DC-VOLTAGE RESPONSE OF DSTATCOM

Muhannad Drak ALSEBAI [1], Kishore Kumar PEDAPENKI[2]

The widespread of the rectified non-linear loads affect the power quality in the distribution systems. The three-phase four-wire DSTATCOM device is used to improve the power quality in the distribution system. The interval type II fuzzy logic controller has used recently to control DSTATCOM device. In this paper, interval type II fuzzy logic-based unit voltage template based DSTATCOM device to improve the power quality is simulated via MATLAB, and the results compared with the other common interval type II fuzzy logic control algorithms. The tunning process of interval type II fuzzy logic-based on different control algorithms including the unit voltage template theory and in the respect of different load situations is explained. The utilization of interval type II fuzzy logic with unit voltage template control algorithm improves the DC capacitor voltage response of DSTATCOM device in comparison with the other interval type II fuzzy logic control algorithms.

Keywords: Unit Voltage Template control algorithm, Interval Type II Fuzzy Logic Controller, DC Capacitor Voltage Response Improvement, DSTATCOM Device

1. Introduction

The excessive use of electronics appliances these days consumes a lot of reactive power demanding to increase the size of distribution grid unless the compensating process of the reactive power [1]. Besides, the penetration of renewable energy causes power quality issues in the distribution grids such as harmonic current, source neutral current and power factor reduction, [2,3]. The reliability of the distribution grid and the necessity to provide the customers with a pure three-phase currents increase the need of the utilization of power quality improvement devices [4,5].

Flexible Alternating Current Transmission Systems DFACTS device is very sensitive for electrical grid condition changes and has the ability to maintain the reliability of the power supplied by the electrical source [6]. Static Compensator STATCOM monitors the reactive power transmitted between the load and the electrical source which causes the voltage fluctuation and generates the necessary reactive power to regulate the voltage [7]. Distributed static compensator,

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DSTATCOM Device, considered as a current quality improvement device, which is connected in shunt to enhance the power quality. Dynamic voltage restorer, DVR Device, considered as a voltage quality improvement device, which is connected in series with load to enhance the power quality. The Unified power quality conditioner, UPQC Device, considered as a current and voltage quality improvement device, which is connected in shunt and series with load for improving the power quality [8]. DSTATCOM device is considered as one of the best power quality improvement devices for the load changing conditions [9]. Three-phase four-wire DSTACOM device eliminates the neutral currents caused by unbalanced loads in the distribution grids keeping the three-phase source currents balanced. [10,11].

There are many control algorithms used recently to control the DC capacitor voltage of DSTATCOM device such as instantaneous reactive power theory, unit voltage template and synchronous reference frame theory [12]. In [13], the author used a new control algorithm root counting and signatures for controlling STATCOM device. Many researchers recently put much effort for improving control algorithms such as, a New Grey Wolf optimization algorithm, which tunes the parameters of fuzzy logic controller leading to the distribution grid stability increment [14]

The regulations of PI controller tunning process are explained in many papers [15,16]. A new PI controller for increasing the voltage stability is used to control STATCOM by generating 48 pulses necessary for voltage source converter VSC in [7]. The authors utilized a new technique of control algorithm which has the ability to adjust PI gains making it as adaptive algorithm [17]. Also, the adaptive PI can be reached by employing fuzzy logic which used in instantaneous PI tuning process in the regard to the load [18,19] The main purpose of using type I fuzzy logic to control STATCOM is to reach the power distribution stability [20]. Type I fuzzy logic is easy to implement and considered as a solution for complicated control algorithms, but the programmer needs to select the inputs and rules carefully to avoid using costly hardware [21,22]. The regulations of the tunning process of type I fuzzy-logic-based unit voltage template algorithm to control shunt active power is presented in [23]. The increment of the interval type I fuzzy logic input membership functions improves THD of the source currents and keeps it in very reduced rate [24]. The optimized fuzzy logic controller is achieved by using genetic algorithm for improving the efficiency of DSTATCOM device in the transient situation is explained in [25]. The adaptive fuzzy logic type I examined in different abnormal situations in [26]. The application of adaptive fuzzy logic PID controller and how to use it for controlling the speed of wind turbine is examined in [27]. Zadeh, in [28], discussed the disadvantages of interval type I fuzzy logic and gave interval type II fuzzy logic as a solution of the uncertainty. The utilization of interval type II fuzzy logic can deal with the uncertain data and decreases the size of the hardware used because it uses a reduced input upper and lower membership functions. The instructions how to activate interval type II fuzzy logic and examples how it works is presented in [29]. The researchers started to apply fuzzy logic type II for controlling STATCOM device to enhance many aspects such as voltage changing mitigation, stabilize of voltage during faults and reducing voltage variations in PV generations [30,31,32]. The researcher started to compare the interval type I fuzzy logic with the interval type II fuzzy logic for controlling DSTATCOM device as in [33]. STATCOM device with Interval type II fuzzy logic controller is connected to the high voltage bar to improve the power quality with low voltage load and high voltage loads at the same time is explained in [34].

In this paper, the application of interval type II fuzzy logic with unit voltage template control algorithm takes place by using MATLAB environment®. The instructions how to tune the interval type II fuzzy logic in the respect different load situations are given to keep the efficiency of the DSTATCOM device in mitigation the harmonics and improving the source power factor. The comparison between the different control algorithms with different range of error and change of error inputs, depending on the DC capacitor voltage response and source current THD, were included in this paper to examine the efficiency of the new interval type II fuzzy logic-based unit voltage template control algorithm.

2. DSTATCOM three-phase four-wire Device

DSTATCOM device is one of the DFACTS devices that integrated in parallel with load to improve the power quality instantaneously. It contains of Voltage Source Inverter VSI, interface inductor L_f, DC capacitor C_{DC}, and it needs control algorithm which measures the parameters of electrical grid instantaneously and provide the VSI with the pulses needed to improve the power quality of the source. Fig. 1 illustrates the DSTATCOM device utilized in this paper. The DSTATCOM utilized in this paper has the same structure of three-phase three-wire DSATCOM device, but with one difference, which is the utilization of two more IGBT thyristors of the neutral line. This type of DSTATCOM device used with unbalanced loads to keep the three-phase source currents pure and balanced. The DSTATCOM device parameters utilized in this paper for different load situations are mentioned in the Table 1 [35].

Table 1

The DSTATCOM device Parameter

Magnitude	4 kVA	8 kVA	14 kVA
Capacitor Vdc	700 V	700 V	700 V
Capacitor Cdc	3000 uF	3000 uF	3000 uF
Interface Inductor Lf	21 mH	10 mH	7 mH

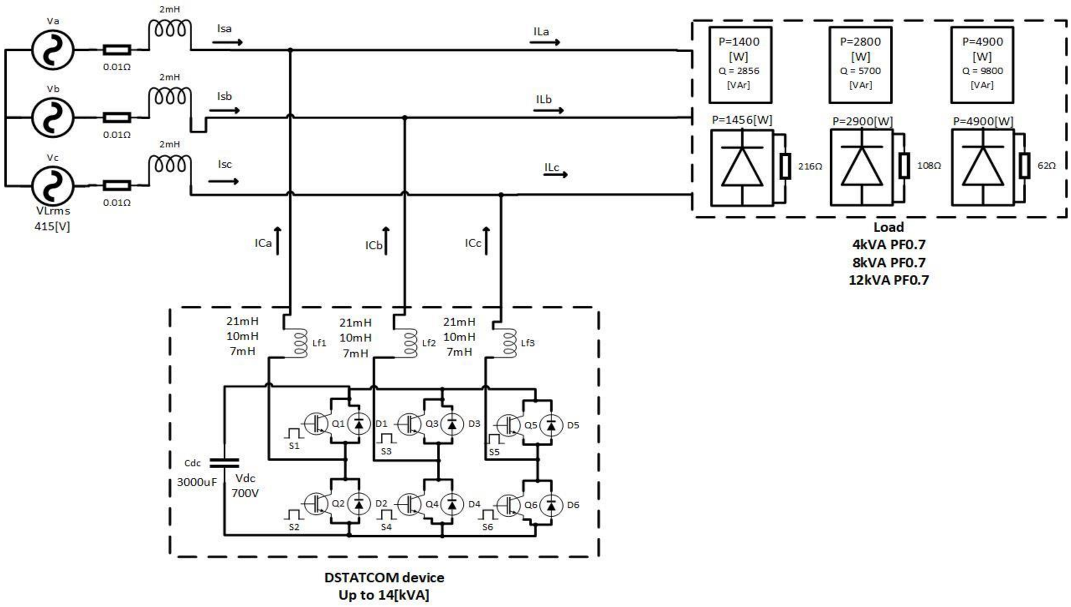

Fig. 1. Electrical grids parameters with DSTATCOM device integrated in parallel

3. Control Algorithms

A. Interval Type II Fuzzy Logic based Instantaneous Reactive Power Theory Control Algorithm:

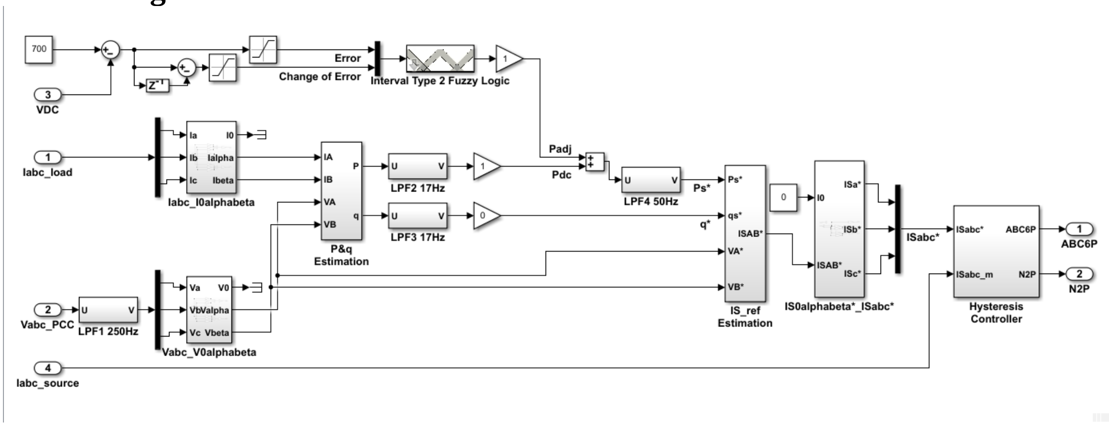

Fig. 2. Interval Type II Fuzzy Logic based IRP Theory

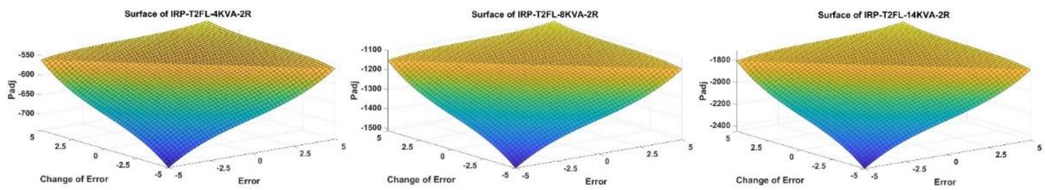

Fig. 3. Surface of Interval type Interval Type II Fuzzy Logic based IRP theory tuned for 4-8-14 kVA with error and change of error three membership functions second range [-5, +5]

The working principal of this theory is to generate reference three-phase source currents and compared them with the measured three-phase source currents in order to generate three error signals, which they are used as inputs for the hysteresis controller to generate three-phase six pulses needed by the DSTATCOM device. The reference active power component Ps* consists of the filtered load active power component Pdc by using low pass filter and the adjusting component extracted by the interval type II fuzzy logic Padj. The reference reactive power component qs* should be at the zero value to make the source power factor at the unity value [36]. See Fig. 2.

Table 2

Interval Type II fuzzy logic-based IRP Theory parameters

Load kVA	Interval Type II fuzzy Logic based IRP Parameters		
	Error	Change of Error	Padj W
4 kVA PF 0.7	[-2,2]	[-2,2]	[-3172,2007]
	[-5,5]	[-5,5]	
8 kVA PF 0.7	[-2,2]	[-2,2]	[-6283,3983]
	[-5,5]	[-5,5]	
14 kVA PF 0.7	[-2,2]	[-2,2]	[-10960,7356]
	[-5,5]	[-5,5]	

The interval type II fuzzy logic keeps the DC capacitor voltage at the reference value by increasing or decreasing the active power generated by the electrical source to cover the active power needed by the load in addition to the lose power consumed in the DSTATCOM device.

In this paper, the interval type II fuzzy based IRP theory tuned to three different loads 4 kVA 8 kVA 14 kVA with PF 0.7. It has two input signals, DSTACOM DC capacitor voltage error signal and DSTACOM DC capacitor voltage error signal change of error signal, and it has one output signal, the adjusting active power signal Padj. The two input signals have three membership functions with two examined ranges [-2,2] [-5,5] which are the same for all different loads, while the output adjusting active power Padj has different ranges in the respect of the different loads [37]. See Fig. 3. The range of Padj output has been selected depending on the output of PI controller-based IRP control algorithm which keeps the DC voltage capacitor at the reference value.

B. Interval Type II Fuzzy Logic based Synchronous Reference Frame Theory Control Algorithm:

The main idea interval type II fuzzy logic based SRF theory is to generate reference three-phase source currents and compared them with the measured three-phase source currents in order to generate three error signals, which they are used as inputs for the hysteresis controller to generate three-phase six pulses needed by the DSTATCOM device. The reference direct component of the source current Isd* consists of the filtered direct load current component Iddc by using low pass filter and the adjusting component extracted by the interval type II fuzzy logic Idadj. The reference quadrature source current component Iqs* should be at the zero value to make the source power factor at the unity value [38]. See Fig. 4.

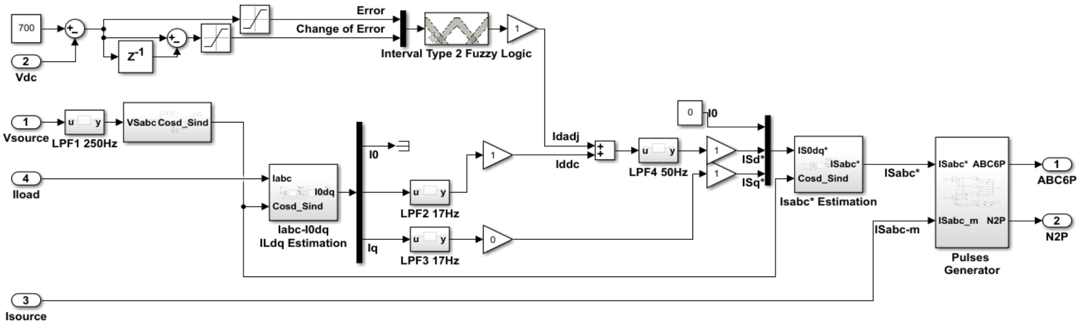

Fig. 4. Interval Type II Fuzzy Logic based SRF Theory Control Algorithm

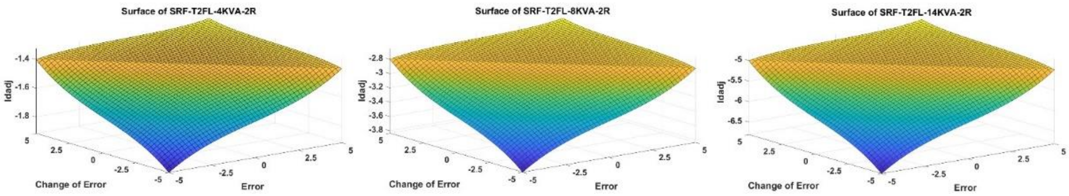

Fig. 5. Surface of Interval type Interval Type II Fuzzy Logic based SRF Theory tuned for 4-8-14 kVA with error and change of error three membership functions second range [-5, +5]

Table 3

Interval Type II fuzzy logic based SRF Theory parameters

Load kVA	Interval Type II fuzzy Logic based SRF Parameters		
	Error	Change of Error	Idadj A
4 kVA PF 0.7	[-2,2]	[-2,2]	[-8.733,5.933]
	[-5,5]	[-5,5]	
8 kVA PF 0.7	[-2,2]	[-2,2]	[-17.47,11.87]
	[-5,5]	[-5,5]	
14 kVA PF 0.7	[-2,2]	[-2,2]	[-30.67,20.67]
	[-5,5]	[-5,5]	

The interval type II fuzzy logic keeps the DC capacitor voltage at the reference value by increasing or decreasing the direct source current component generated by the electrical source to cover the direct current needed by the load in addition to the direct lose current consumed in the DSTATCOM device.

In this paper, the interval type II fuzzy based synchronous reference frame tuned to three different loads 4 kVA 8 kVA 14 kVA with PF 0.7. It has two input signals, error signal and change of error signal, and it has one output signal, the adjusting direct current component signal Idadj. The adjusting direct current component is utilized to decrease or increase the reference direct source current I_{dDC} to keep the DC voltage value at the reference value. The two input signals have three membership functions with two examine ranges [-2,2] [-5,5] which are the same for all different loads, while the output direct current component Idadj has different ranges in the respect of the different loads [39]. See Fig. 5. The range of Idadj output has been selected depending on the output of PI controller based SRF control algorithm which keeps the DC voltage capacitor at the reference value.

C. Interval Type II Fuzzy Logic based unit voltage template Theory Control Algorithm:

The main idea interval type II fuzzy logic-based UVT theory is to generate reference three-phase source currents and compare them with the measured three-phase source currents in order to generate three error signals, which they are used as inputs for the hysteresis controller to generate three-phase six pulses needed by the DSTATCOM device. The reference three-phase source currents should have the same phase of the source three-phase voltages to keep the source power factor at the unity value, while the reference three phase source currents should have the amplitude generated by the interval type II fuzzy logic ISp* [40]. See Fig. 6.

Table 4

Interval Type II fuzzy logic-based unit voltage template theory parameters

Load kVA	Interval Type II fuzzy Logic based UVT Parameters		
	Error	Change of Error	ISp* A
4 kVA PF 0.7	[-2,2]	[-2,2]	[-2.133,12.53]
	[-5,5]	[-5,5]	
8 kVA PF 0.7	[-2,2]	[-2,2]	[-3.867, 25.47]
	[-5,5]	[-5,5]	
14 kVA PF 0.7	[-2,2]	[-2,2]	[-3, 41]
	[-5,5]	[-5,5]	

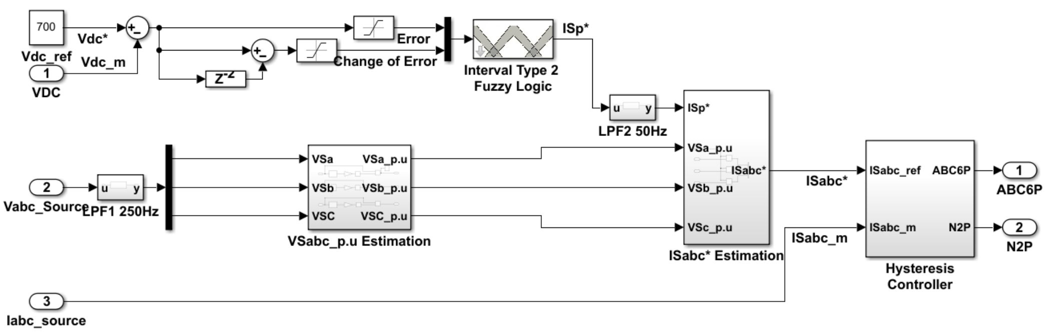

Fig. 6. Interval Type II Fuzzy Logic based UVT theory Control Algorithm

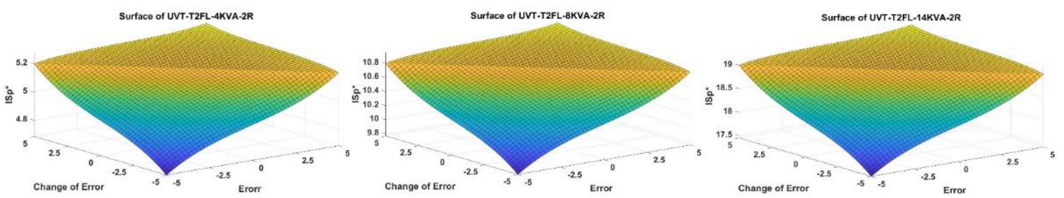

Fig. 7. Surface of Interval type Interval Type II Fuzzy Logic based UVT tuned for 4-8-14 kVA with error and change of error three membership functions second range [-5, +5]

The interval type II fuzzy logic keeps the DC capacitor voltage at the reference value by increasing or decreasing the amplitude of three-phase source currents generated by the electrical source to cover the amplitude of three-phase load currents in addition to the amplitude of the three-phase lose currents consumed in the DSTATCOM device. The range of ISp* output has been selected depending on the output of PI controller based UVT control algorithm which keeps the DC voltage capacitor at the reference value.

In this paper, the interval type II fuzzy based unit voltage template tuned to three different loads 4 kVA 8 kVA 14 kVA with PF 0.7. It has two input signals, error signal and change of error signal, and it has one output signal, the amplitude of the three-phase source currents signal ISp*. The two inputs have three membership functions with two examine ranges [-2,2] [-5,5] which are the same for all different loads, while the amplitude of the three-phase source currents ISp* has different ranges in the respect of the different loads. See Fig. 7. As Fig. 8 illustrates, the Sugeno interval type II fuzzy logic is utilized with UVT at load 14 kVA. The type-reduction method is ‘eiasc’, the defuzzification method used is ‘wtaver’ [29,42]. The two inputs have three lower and upper membership functions of the type ‘gaussmf’ with the second range [-5,5]. There are nine rules utilized as the follows,

Table 5

The nine rules utilized in IT2FL based UVT at 14kVA

CE/E	Low	Normal	High
Low	Low	Low	Normal
Normal	Low	Normal	High
High	Normal	High	High

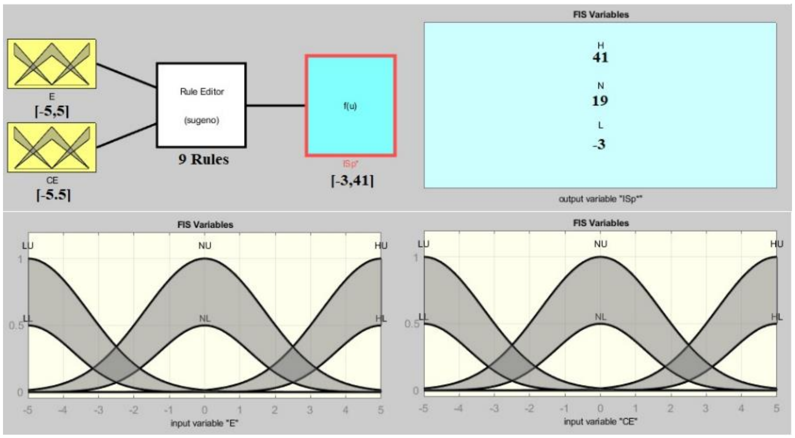

Fig. 8. Interval type II fuzzy logic controller based UVT at load 14 kVA

4. Simulation and Results

MATALB Simulink Environment® used to examine the proposed control algorithm in comparison with other control algorithms to find out the improvement in DC capacitor voltage response of DSTATCOM device. As Fig. 9 shows, the targeted electrical grid contains of low voltage electrical source side, DSTATCOM device connected to distribution grid at the point of common coupling and low voltage load side with different load situations. The control algorithm examined in this paper are T2FL based IRP theory tuned to the different load situations, T2FL based SRF theory tuned to the different load situations and T2FL based UVT theory tuned to the different load situations. These different control algorithms with two ranges of input signals [-2,2] [-5,5] were examined with different load situations to figure out the optimized control algorithm with the application of interval type II fuzzy logic for controlling DSTACOM device.

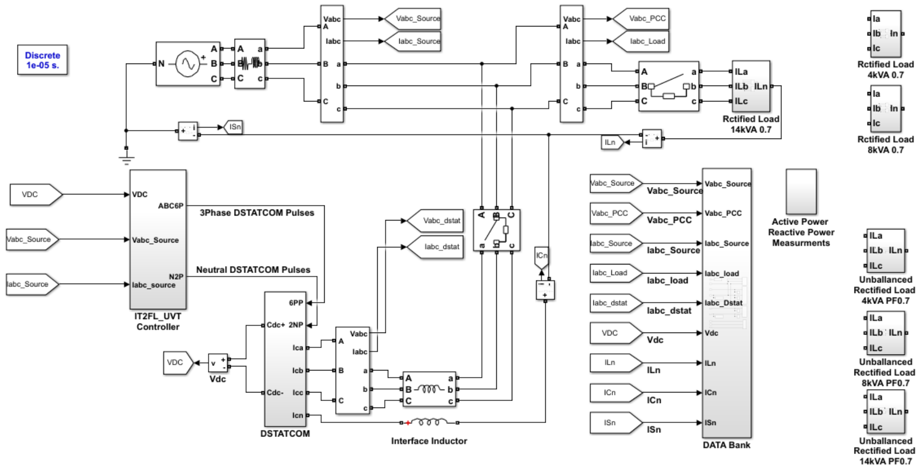

Fig. 9. Electrical gird which consists of, low voltage electrical source, low voltage distribution grid, different load situations, DSTATCOM device with UVT-T2FL Control algorithm.

A. Different Load Situations:

1. Error and change of error with three membership functions first range:

Table 5

Capacitor DC voltage signal response comparison at Different Load Situations with error and change of error first range

Controller	Apparent Power kVA	Capacitor dc Voltage Parameter				
		Rising time ms	Peak time ms	Settling time ms	Overshoot%	Peak V
IRP_T2FL	4 kVA PF 0.7	89.5	205	210	0.07%	700.5
SRF_T2FL		84.4	186	190	0.14%	701
UVT_T2FL		79.5	169	180	0.14%	701
IRP_T2FL	8 kVA PF 0.7	44	105	120	0.21%	701.5
SRF_T2FL		42	95	110	0.21%	701.5
UVT_T2FL		37	80	90	0.28%	702
IRP_T2FL	14 kVA PF 0.7	27.5	66	70	0.28%	702
SRF_T2FL		26.5	60	68	0.28%	702
UVT_T2FL		24.5	53	62	0.5%	704

Table 6

Source current THD and Source PF comparison at at different constant loads with error and change of error first range

Controller	Apparent Power kVA	Electrical Source Parameter			
		Is THD	Ps W	Qs Var	Source PF
W/O DSTATCOM	4 kVA PF 0.7	11.03%	2840	2810	0.7
IRP_T2FL		4.30%	2860	535	0.98
SRF_T2FL		4.21%	2860	535	0.98
UVT_T2FL		4.22%	2860	535	0.98
W/O DSTATCOM	8 kVA PF 0.7	10.89%	5660	5620	0.7
IRP_T2FL		3.87%	5680	1080	0.98
SRF_T2FL		3.86%	5680	1080	0.98
UVT_T2FL		3.83%	5680	1080	0.98
W/O DSTATCOM	14 kVA PF 0.7	10.95%	9820	9650	0.7
IRP_T2FL		3.52%	9850	1880	0.98
SRF_T2FL		3.49%	9850	1880	0.98
UVT_T2FL		3.53%	9850	1880	0.98

The IT2FL with first range input signals [-2,2] based on different control algorithms used to control DSTATCOM device in different load situations. First, at the load 4 kVA PF 0.7; IT2FL based UVT in comparison with IT2FL based IRP/SRF improves the DC capacitor response as follows, RT 79.5 ms, PT 169 ms and ST 180 ms; increases the overshoot to the value 701 V; maintains the THD of the source current at almost the same value 4.22%; maintains the source power factor at the value of 0.98. Second, at the load 8 kVA PF 0.7; IT2FL based UVT in comparison with IT2FL based IRP/SRF improves the DC capacitor response as follows, RT 37 ms, PT 80 ms and ST 90 ms; increases the overshoot to the value 702 V; decreases the THD of the source current to value 3.83%; maintains the source power factor at the value of 0.98. Third, at the stable load 14 kVA PF 0.7; IT2FL based UVT in comparison with IT2FL based IRP/SRF improves the DC capacitor response as follows, RT 24.5 ms, PT 53 ms and ST 62 ms; increases the overshoot to the value 704 V; maintains the THD of the source current at the value 3.53%; maintains the source power factor at the value of 0.98. The utilization of IT2FL based UVT with the first range input signals [-2,2] in comparison with IT2FL based IRP/SRF improves the DC capacitor voltage response; and it doesn't affect the efficiency of DSTATCOM device in the mitigation of the harmonics and in improving the source power factor at the different stable loads.

2. Error and change of error with three membership functions second range:

Table 7

Capacitor DC voltage signal response comparison at different load situations with error and change of error second range

Controller	Apparent Power kVA	Capacitor dc Voltage Parameter				
		Rising time ms	Peak time ms	Settling time ms	Overshoot%	Peak V

IRP_T2FL	4 kVA PF 0.7	89.5	206	206	0%	700
SRF_T2FL		84.4	186	186	0%	700
UVT_T2FL		79.5	170	180	0%	700
IRP_T2FL	8 kVA PF 0.7	44	110	120	0.14%	701
SRF_T2FL		41	95	105	0.14%	701
UVT_T2FL		36	82	90	0.28%	702
IRP_T2FL	14 kVA PF 0.7	27.5	66	75	0.35%	702.5
SRF_T2FL		26.5	62	68	0.42%	703
UVT_T2FL		23.5	53	62	0.5%	703.5

Table 8

Source current THD and Source PF comparison at at different constant loads with error and change of error second range

Controller	Apparent Power kVA	Electrical Source Parameter			
		Is THD	Ps W	Qs Var	Source PF
W/O DSTATCOM	4 kVA PF 0.7	11.03%	2840	2810	0.7
IRP_T2FL		4.35%	2860	535	0.98
SRF_T2FL		4.27%	2860	535	0.98
UVT_T2FL		4.27%	2860	535	0.98
W/O DSTATCOM		10.89%	5660	5620	0.7
IRP_T2FL	8 kVA PF 0.7	3.72%	5680	1080	0.98
SRF_T2FL		3.52%	5680	1080	0.98
UVT_T2FL		3.76%	5680	1080	0.98
W/O DSTATCOM		10.95%	9820	9650	0.7
IRP_T2FL	14 kVA PF 0.7	3.26%	9850	1880	0.98
SRF_T2FL		3.21%	9850	1880	0.98
UVT_T2FL		3.08%	9850	1880	0.98

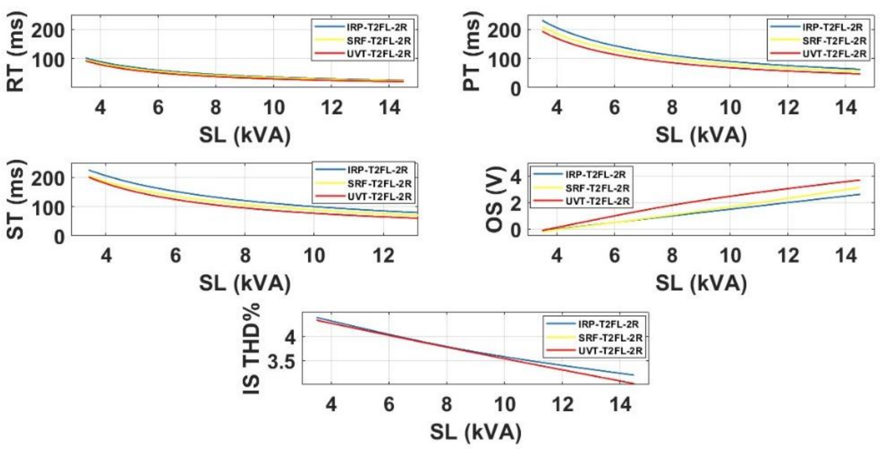

Fig. 10. DC voltage capacitor response, rising time RT, peak time PT, sitting time ST, over shoot OS as function to load apparent power SL; Source current total harmonic distortion IS THD% as a function to load apparent power SL with error and change of error three membership functions second range.

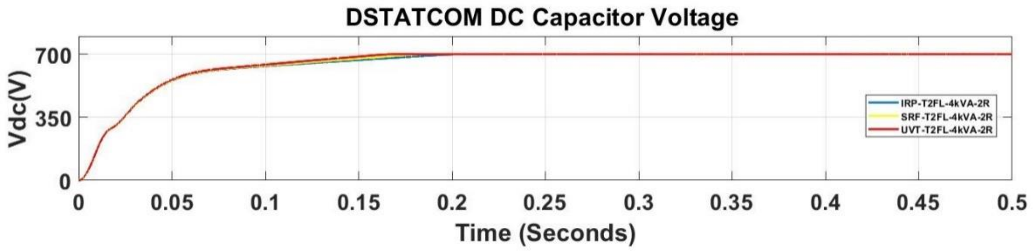

Fig. 11. DSTATCOM Capacitor DC Voltage response at load apparent power 4 kVA PF 0.7 with error and change of error three membership functions second range.

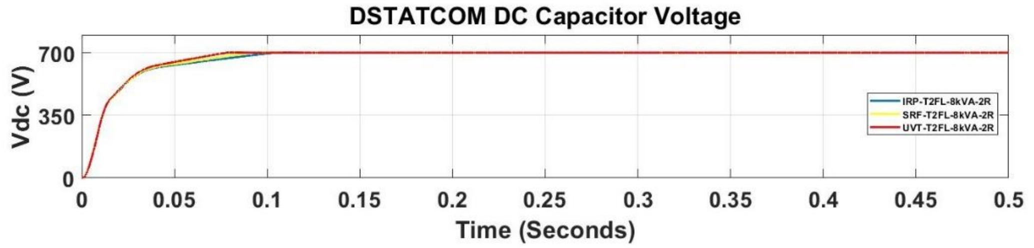

Fig. 12. DSTATCOM Capacitor DC Voltage response at load apparent power 8 kVA PF 0.7 with error and change of error three membership functions second range.

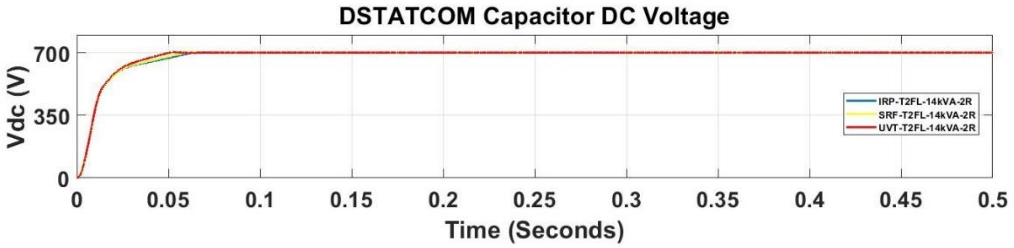

Fig. 13. DSTATCOM Capacitor DC Voltage response at load apparent power 12 kVA PF 0.7 with error and change of error three membership functions second range.

The interval type II fuzzy logic with second range input signals [-5,5] based on different control algorithms used to control DSTATCOM device in different load situations. First, at the load 4 kVA PF 0.7; IT2FL based UVT second range input signals [-5,5] in comparison with IT2FL based UVT with first range input signals [-2,2] maintains the DC capacitor response at the same values, RT 79.5 ms, PT 170 ms and ST 180 ms; decreases the overshoot to value of 700 V; increases the THD of the source current to the value 4.27%; maintains the source power factor at the value of 0.98. See Fig. 11. Second, at the stable load 8 kVA PF 0.7; IT2FL based UVT second range input signals [-5,5] in comparison with IT2FL based UVT with first range input signals [-2,2] maintains the DC capacitor response at the same values 36 ms, 82 ms and 90 ms respectively; maintains the overshoot at value of 702 V; decreases the THD of the source current in good margin to the value 3.76%; maintains the source power factor at the value of 0.98. See Fig. 12. Third, at the stable load 14 kVA PF 0.7; IT2FL based UVT second range input signals [-5,5] in comparison with IT2FL based UVT with first range input signals [-2,2] maintains the DC capacitor response at the same values, RT 23.5 ms, PT 53 ms and ST 62 ms; decreases the overshoot to value of 703.5 V; decreases the THD of the source current in good margin to the value 3.08%; maintains the source power factor at the value of 0.98. See Fig. 13. The utilization of IT2FL based UVT with second range input signals [-5,5] in comparison with IT2FL based UVT with the first range input signals [-2,2] maintains the DC capacitor voltage response at almost the same value; it doesn't affect the efficiency of DSTATCOM device in improving the source power factor; but it improves the efficiency of DSTATCOM device in the mitigation of the harmonics at the different stable loads. See Fig. 14.

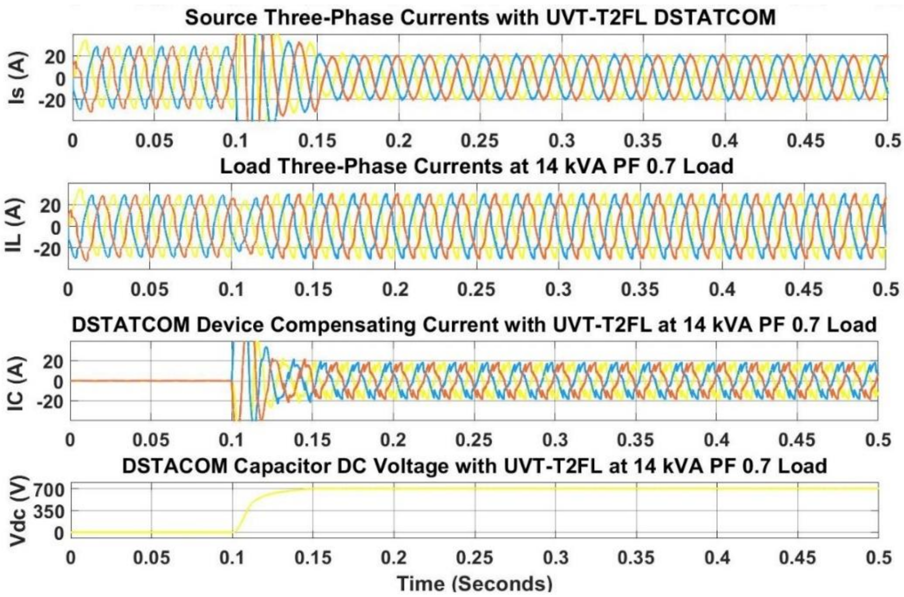

Fig. 14. Electrical grid waveforms at the rectified nonlinear load of 14 kVA PF0.7 while using UVT_T2FL with error and change of error three membership functions second range based DSTATCOM device for compensating starting from t=0.1 s

5. Conclusion

The interval type II fuzzy logic-based unit voltage template is utilized in this paper for improving the DC capacitor voltage response in different load situations. According to the results, the main contribution of this paper as follows (i) The instructions of tuning process of different interval type II fuzzy logic control algorithms in the regards of different load situations is produced. (ii) The interval type II fuzzy logic-based unit voltage template succeed in the mitigation of the harmonics and improving the DC capacitor voltage response (iii) The interval type II fuzzy logic-based unit voltage template control algorithm is better than the interval type II fuzzy logic-based instantaneous reactive power and synchronous reference frame control algorithms (iv) The interval type II fuzzy logic with error and change of error three membership functions second range [-5,5] is better than the interval type II fuzzy logic with error and change of error three membership functions first range [-2,2].

R E F E R E N C E S

[1] Singh, B., Solanki, J. "A Comparison of Control Algorithms for DSTATCOM," in IEEE Transactions on Industrial Electronics, vol. 56, no. 7, pp. 2738-2745, July 2009, doi: 10.1109/TIE.2009.2021596.

[2] Sreenivasarao, D., Agarwal, P., Das, B. “Neutral current compensation in three-phase, four-wire systems: A review,” Electric Power Systems Research, vol. 86, pp. 170–180, 2012.

[3] Hossain, E., Tür, M. R., Padmanaban, S., Ay, S., Khan, I. “Analysis and mitigation of power quality issues in distributed generation systems using custom power devices,” Ieee Access, vol. 6, pp. 16 816–16 833, 2018

[4] Pandu, S. B., Sundarabalan, C. K., Srinath, N. S., Krishnan, T. S., Priya, G. S., Balasundar, C., Sharma, J., Soundarya, G., Siano, P., Alhelou, H. H. "Power Quality Enhancement in Sensitive Local Distribution Grid Using Interval Type-II Fuzzy Logic Controlled DSTATCOM," in IEEE Access, vol. 9, pp. 59888-59899, 2021, doi: 10.1109/ACCESS.2021.3072865.

[5] Bert, R. ``Power quality issues and the effects on medical equipment," J. Clin. Eng., vol. 22, no. 1, pp. 35-40, Jan. 1997.

[6] Ponmurugavel, P. S., Ghouse, S. M. "Design and modeling of fuzzy and model predictive controllers for STATCOM to enhance transient stability of power system", International Journal of Engineering and Technology, 5(3), pp. 2609–2619, 2013.

[7] Xi, Z., Bhattacharya, S. "STATCOM Control and Operation with Series Connected Transformer Based 48-pulse VSC", In: IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society, Taipei, Taiwan, 2007, pp. 1714–1719. ISBN 1-4244-0783-4

[8] Singh, B., Jayaprakash, P., Kothari, D.P. ‘New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply voltage conditions based on synchronous reference frame theory’, International Journal of Electrical Power & Energy Systems, Volume 33, Issue 5, 2011, Pages 1109-1117, ISSN 0142-0615,

[9] Sundarabalan, C. K., Selvi, K. ’PEM fuel cell supported distribution static compensator for power quality enhancement in three-phase four-wire distribution system’ Int. J. Hydrogen Energy, vol. 39, no. 33, pp. 19051_19066, Nov. 2014

[10] Singh, B., Jayaprakash, P., Kothari, D. P., Chandra, A., Haddad, K. A. "Comprehensive Study of DSTATCOM Configurations," in IEEE Transactions on Industrial Informatics, vol. 10, no. 2, pp. 854-870, May 2014, doi: 10.1109/TII.2014.2308437.

[11] Gruzs, T. M. “A survey of neutral currents in three-phase computer systems,” IEEE Trans. Ind. Appl., vol. 26, no. 4, pp. 719–725, Jul./Aug. 1990.

[12] K. K. Pedapenki, S. P. Gupta and M. K. Pathak, "Soft control techniques for shunt active power filter," *2015 IEEE Power, Communication and Information Technology Conference (PCITC)*, 2015, pp. 60-65, doi: 10.1109/PCITC.2015.7438075.

[13] Pang, C., Kezunovic, M. "A new approach to PID controller design of STATCOM", In: 2008 40th North American Power Symposium, Calgary, AB, Canada, 2008, pp. 1–6.

[14] Shi, J., Noshadi, A., Kalam, A., Shi, P. "Fuzzy logic control of DSTATCOM for improving power quality and dynamic performance", In: 2015 Australasian Universities Power Engineering Conference (AUPEC), Wollongong, NSW, Australia, 2015, pp. 1–6. ISBN 978-1-4799-8725-2. https://doi.org/10.1109/AUPEC.2015.7324796

[15] Shaaban, F., Harmoosh, Z., Alsari, E. "Enhancement of voltage stability in power transmission networks using static compensator (STATCOM) based on fuzzy logic", Tishreen University Journal for Research and Scientific Studies - Engineering Sciences Series, 39(3), pp. 387–404, 2017.

[16] Kumar, N. M. G., Sangameswara Raju, P., Venkatesh, P. "Control of DC Capacitor Voltage in a DSTATCOM using Fuzzy Logic Controller", International Journal of Advances in Engineering & Technology, 4(1), pp. 679–690, 2012.

[17] Xu, Y., Li, F. "Adaptive PI Control of STATCOM for Voltage Regulation", IEEE Transactions on Power Delivery, 29(3), pp. 1002–1011, 2014. https://doi.org/10.1109/TPWRD.2013.2291576

[18] Kumar, K. S., Gopal, N. V. "Improvement of DC link voltage in D-Statcom based on Fuzzy logic", The International Journal Of Engineering and Science (IJES), 2(12), pp. 77–84, 2013

[19] Ghantimath, A. S., Vinayak, K. U. "Design and Simulation of DSTATCOM using Fuzzy Logic Controller", International Research Journal of Engineering and Technology (IRJET), 8(1), pp. 157–163, 2021.

[20] Sagar, S., Satti, R. "Fuzzy Logic Control of D-STATCOM for Improving Power Quality and Dynamic Performance", International Journal of Innovative Technologies, 6(2), pp. 0487–0490, 2018.

[21] Pedapenki, K. K., Gupta, S. P., Pathak, M. K. ‘Shunt Active Power Filter with MATLAB and d’SPACE 1104 Verification’, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 6 (2016) pp 4085-4090

[22] Pedapenki, K. K., Gupta, S. P., Pathak, M. K. "Comparison of PI & fuzzy logic controller for shunt active power filter," 2013 IEEE 8th International Conference on Industrial and Information Systems, 2013, pp. 42-47, doi: 10.1109/ICIInfS.2013.6731952

[23] Singh, J.P., Singh, A. "Implementation of Fuzzy Log DSTATCOM for Power Qua Distribution Sy.", International Research Journal of Engineering and Applied Science, P.9, (2022), 10.55083/irjeas.2022.v10i03001.

[24] Pedapenki, K. K., Gupta, S. P., Pathak, M. K. "Two controllers for shunt active power filter based on fuzzy logic," 2015 IEEE International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), 2015, pp. 141-144, doi: 10.1109/ICRCICN.2015.7434225.

[25] Aprem, A. A., Chacko, F. M. "Harmonic compensation using fuzzy controlled DSTATCOM", International Journal of Engineering Research and General Science, 3(5), pp. 1112–1129, 2015.

[26] Mahmood, A. K., Ali, I. I., Al-Gailany, A. A. "Voltage stability improvements using adaptive controller for STATCOM", Journal of Engineering and Sustainable Development, 21(2), pp. 129–148, 2017.

[27] Hamoodi, S. A., Hameed, F. I., Hamoodi, A. N. "Pitch Angle Control of Wind Turbine Using Adaptive Fuzzy-PID Controller", EAI Endorsed Transactions on Energy Web, 7(28), e15, 2020. https://doi.org/10.4108/eai.13-7-2018.165500

[28] Zadeh, L. A. "The concept of a linguistic variable and its application to approximate reasoning—I", Information Sciences, 8(3), pp. 199–249, 1975. https://doi.org/10.1016/0020-0255(75)90036-5

[29] Taskin, A., Kumbasar, T. "An Open-Source Matlab/Simulink Toolbox for Interval Type-2 Fuzzy Logic Systems," 2015 IEEE Symposium Series on Computational Intelligence, 2015, pp. 1561-1568, doi: 10.1109/SSCI.2015.220.

[30] Hong, Y. Y., Hsieh, Y. L. "Interval Type-II Fuzzy Rule-Based STATCOM for Voltage Regulation in the Power System", Energies, 8(8), pp. 8908–8923, 2015.

[31] Vivekanand, G., Chandra Sekhar, K., Suresh, D. "Type2 Fuzzy Logic Controlled Adjustable Step-Size LMS Algorithm for DSTATCOM", International Journal of Engineering & Technology, 7(3.27), pp. 531–534, 2018. https://doi.org/10.14419/ijet.v7i3.27.18487

[32] Hong, Y. Y., Liu, M. "Optimized Interval Type-II Fuzzy Controller-Based STATCOM for Voltage Regulation in Power Systems With Photovoltaic Farm", IEEE Access, 6, pp. 78731–78739, 2018. https://doi.org/10.1109/ACCESS.2018.2885198

[33] Henini, N., Benzerafa, F., Tlemçani, A., Sebaa, K. "Type-1 and Type-2 Fuzzy Logic Controller Based Multilevel DSTATCOM Using SVM", Studies in Informatics and Control, 25(1), pp. 87–98, 2016. https://doi.org/10.24846/v25i1y201610

[34] Kadri, A., Makhloufi, S. "Interval Type2 Fuzzy Logic Based STATCOM Controller for Stabilizing a Mixed Electrical Network System", Periodica Polytechnica Electrical Engineering and Computer Science, 2022.
[35] _Alsebai, M. D., Kamala, N. ‘Source Current-Voltage Loop Based Instantaneous Reactive Power Theory Control Algorithm Based Dstatcom For Power Quality Improvement’, U.P.B. Sci. Bull., Series C, Vol. 84, Iss. 2, Pp.337-352, 2022, Issn 2286-3540
[36] Akagi, H., Kanazawa, Y., Nabae, A. "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components," in IEEE Transactions on Industry Applications, vol. IA-20, no. 3, pp. 625-630, May 1984, doi: 10.1109/TIA.1984.4504460, https://doi.org/10.1109/TIA.1984.4504460
[37] Pedapenki, K. K., Gupta, S. P., Pathak, M. K. "Neuro Fuzzy Based Controller for Power Quality Improvement," 2015 International Conference on Computational Intelligence and Communication Networks (CICN), 2015, pp. 1294-1298, doi:10.1109/CICN.2015.248, https://doi.org/10.1109/CICN.2015.248
[38] Benhabib, M.C., Saadate, S. ‘New control approach for four-wire active power filter based on the use of synchronous reference frame’, Electric Power Systems Research, Volume 73, Issue 3, 2005, Pages 353-362, ISSN 0378-7796. https://doi.org/10.1016/j.epsr.2004.08.012
[39] Sundaram, E., Venugopal, M. ‘On design and implementation of three phase three level shunt active power filter for harmonic reduction using synchronous reference frame theory’, International Journal of Electrical Power & Energy Systems, Volume 81, 2016, Pages 40-47, ISSN 0142-0615.
[40] Pedapenki, K. K., Swathi, G. "Analysis of shunt active power filter with unit voltage template method," 2017 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC), 2017, pp. 749-753, doi: 10.1109/ICCPEIC.2017.8290463.
[41] Drak Alsebai, M. and Pedapenki, K. K. “Transformation of Type I Fuzzy Logic into Interval Type II Fuzzy Logic-based Unit Voltage Template with Controlled Load”, Periodica Polytechnica Electrical Engineering and Computer Science, 2023. https://doi.org/10.3311/PPee.22465
[42] M. D. Alsebai and K. K. Pedapenki, "Sugeno/ Mamdani Interval Type II Fuzzy Logic Controller Based DSTATCOM with Controlled Load," 2023 International Conference on Smart Systems for applications in Electrical Sciences (ICSSES), Tumakuru, India, 2023, pp. 1-6, doi: 10.1109/ICSSES58299.2023.10200807.