

## Transient Power Quality Performance of Multi Photovoltaics using MPPT P and O/MPPT Fuzzy

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### Abstract

*This paper presents comparative performance of transient power quality due to multi photovoltaic (PV) integration to grid at both fixed temperature and solar irradiation connected using Maximum Power Point Tracking Perturb and Observe (MPPT P and O)/MPPT Fuzzy. This research is performed as five transient of short-circuit faults on point common coupling (PCC) bus. An artificial intelligence with fuzzy logic controller (FLC) is used to set duty cycle with step variable to control DC/DC boost converter, generate quick convergence to determine MPPT for controlling of PV output voltage. Furthermore the result is compared with MPPT P and O. During transient phase, non-symmetrical faults are able to result an unbalance current/voltage greater than symmetrical faults. On symmetrical faults, MPPT Fuzzy is able to result an average THD voltage/THD current smaller than MPPT P and O. Otherwise on non-symmetrical faults, MPPT P and O is able to result an average THD voltage/THD current slightly smaller than MPPT Fuzzy. Both of MPPT P and O and MPPT Fuzzy on all short circuit faults during transient phase are able to result significantly smaller current average THD current than average THD voltage and limits of THD prescribed in IEEE 519. This research is simulated using Matlab/Simulink environment.*

**Keywords:** MPPT fuzzy, MPPT P and O, multi photovoltaics, power quality, short circuit, transient

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### 1. Introduction

The PV beside being able to generate power, it also results harmonics due to inverter as a medium to convert DC into AC voltage and is capable to decrease power quality. The short circuit fault can cause rise of current and voltage drop in certain phases depend on fault types, so it is able to generate unbalance voltage and current on low voltage distribution network (grid). The research on power quality of PV connected grid to power system using LCL filter has been done KonKengWenget. al. A number of power quality problems i.e. over voltage, less voltage, power fluctuations, inrush currents, low power factor, and current harmonics or THD will appear on microgrid power system. This research is conducted only on constant solar irradiance and temperature condition (1000 W/m<sup>2</sup> and 25°C) as environmental input parameters for PV systems [1]. The study on effect of solar radiation on grid connected to PV generator to power quality has been investigated by Minas Patsalides, et.al. It considers two different scenarios of average and low radiation [2]. Investigation of grid connected a single phase PV inverter using a current proportional resonant, proportional resonant integral, and genetic algorithm using an active filter to reduce current harmonics of inverter output has been studied by Renuet. al. The laxity of research is only done on a single phase PV and certain irradiance and temperature [3]. The dynamic analysis of power quality due to high penetration effect of distribution network connected to PV under variable irradiance has been studied by MassoudFarhoodnea, et. al. The result showed that high level penetration of grid connected PV will cause a number of power quality problems. However, the research was only analyzed on voltage harmonics and did not consider the ambient temperature condition [4]. Power quality characteristics in a number of three phase PV inverters at top roof PV has been performed by K.P. Kontogianis, et. al [5]. A comparative study of MPPT between FLC and conventional PI controller has been presented for interfacing PV array with utility grid through a three-phase line-commutated

inverter by Omid Zhoulai Bakhoda, et.al. FLC was dominating PI in many important aspects like i.e., provided active power for grid, output current shape of inverter, grid current and current THD [6]. A grid interfaced solar PV (SPV) power generating system in a 3P4W system has been proposed by Arun Kumar Verma, et.al. This system was used for compensation of neutral current, harmonic currents, reactive power and to provide load balancing [7]. However, both of power quality analysis in both papers was only performed by using single PV. Power quality due to integration of multi units of PV generator connected to three phase grid under variable solar irradiation level has been implemented by Amirullah, et.al. At level of solar irradiation was fixed, the greater number of PV connected to three-phase grid, then average THD of grid voltage/current also increased. At level of solar irradiation increased, average THD of grid voltage/current also increased. The PV in this research was still using MPPT with P and O algorithm and not using intelligent control [8].

Adaptive Neuro-fuzzy Inference System (ANFIS)-based improvement of MPPT P and O for PV under different shading conditions has been investigated by Khaled Bataineh, et.al. The simulation show proposed algorithm efficiently reach MPP under uniform irradiation, sudden changes of irradiation, and partial shading [9]. The method for balancing line current and voltage, due to the presence of distributed generations (DGs) i.e. a number of single phase PV generation units in homes has been presented by Amirullah, et.al. This research shows that the combination of Battery Energy Storage (BES) and three single phase bi-directional inverter able to reduce unbalanced line current/voltage. Otherwise, the combination of both circuit able to increases current/voltage harmonics [10]. Power quality enhancement on low voltage of three phase grid caused by different level of PV integration using MPPT Fuzzy under variabel solar irradiance level on constant temperature and load has been investigated by Amirullah, et.al. It was able to enhance profile of grid voltage and current THD due to different level of integration of PV to three phase grid corresponding with IEEE Standard 519. MPPT Fuzzy was also able to improve input power factor better than MPPT P and O [11]. RachidBelaidi, et.al has proposed a combined system of 3P4W shunt active filter and PV with MPPT P and O, to solve power quality such as harmonic currents, poor power factor, and unbalanced load [12]. Salah Eddine Mankour, et al has investigated on modeling of a PV stand alone power system using two widely-adopted MPPT algorithms, P & O and incremental conductance [13]. Bambang Purwahyudi, et. al has researched design of electrical characteristics of solar PV cell model by using self constructing neural network (SCNN) [14]. Julián A.C.C., et. al has used a mathematical model implemented in Matlab/Simulink to evaluate the performance of building integrated photovoltaic systems (BIPVS) [15]. Ahmad Saudi Samosir, et. al has investigated on modeling and simulation of MPPT used in solar power systems with fuzzy logic [16]. But the researchs on enhancement of power quality and MPPT characteristics for PV were only analyzed in normal condition.

This paper presents comparative performance of power quality due to the multi PV integration at both fixed temperature and solar irradiation levels connected to 380 V and 50 Hz distribution network using MPPT P and O/MPPT Fuzzy controller. The research is performed during transient disturbances of short-circuit fault on PCC bus based on five of short circuit faults. An artificial intelligence method with FLC is used to set duty cycle (D) with step variable to control DC/DC boost converter, generate quick convergence calculation to determine MPPT value for controlling of PV generator output voltage. Futhermore the result is compared with MPPT P and O method. The parameters are voltage/current unbalanced, voltage/current THD on each phase, and voltage/current average THD on PCC bus of three phase grid.

This paper is organized as follow. section 2 presents proposed method i.e. proposed model of single PV using MPPT Fuzzy, model multi PV connected three phase grid under short circuit fault, simulation parameters, equivalent circuit, mathematical, and characteristic curve of PV model, MPPT P and O method, MPPT Fuzzy method, voltage and current harmonics, voltage and current unbalance. Section 3 describes comparative performance of multi PV connected grid under short circuit fault during transient phase to current/voltage unbalance and current/voltage THD of three phase grid using MPPT P and O/MPPT Fuzzy method. In this section, example cases studied are presented and the results are verified with those of Matlab/Simulink. Finally, the paper in concluded in section 4.

2. Research Method

2.1. Proposed Model

Figure 1 shows model of a single PV system connected to a three phase grid. The DC/DC converter circuit consists of a boost converter circuit that serves to raise the DC output voltage from the PV. The DC output voltage of the boost converter circuit is then changed by a three phase DC/AC inverter into an AC voltage to three phase grid. The single PV model is then used as a reference to construct multiple PV models connected to grid through a three phase phase distribution transformer showed in Figure 2. This research uses three model group of PVs with an active power of 100 kW each. Besides connected three phase grid, multi PVs are also connected to three group of three phase loads with 20 kW of active power each. The aim of research is to compare performance of power quality due to the multi PV integration at both fixed temperature and solar irradiation levels connected to distribution network using MPPT P and O/MPPT Fuzzy. The research analysis includes transient disturbances of short-circuit fault on PCC bus based on a number of short circuit faults. An artificial intelligence with FLC is used to set duty cycle (D) with step variable to control DC/DC boost converter, generate quick convergence calculation to determine MPPT value for controlling of PV output voltage, and then its result is compared with MPPT P and O method. The DC/DC converter produces a constant DC voltage as an input for DC/AC inverter using pulse with modulation (PWM).

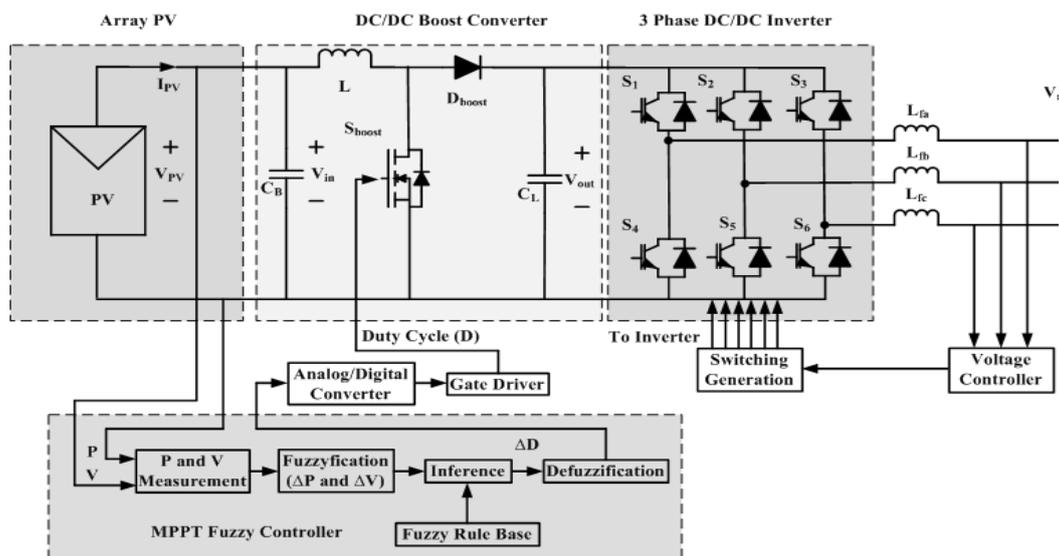


Figure 1. Proposed model of single PV using MPPT fuzzy

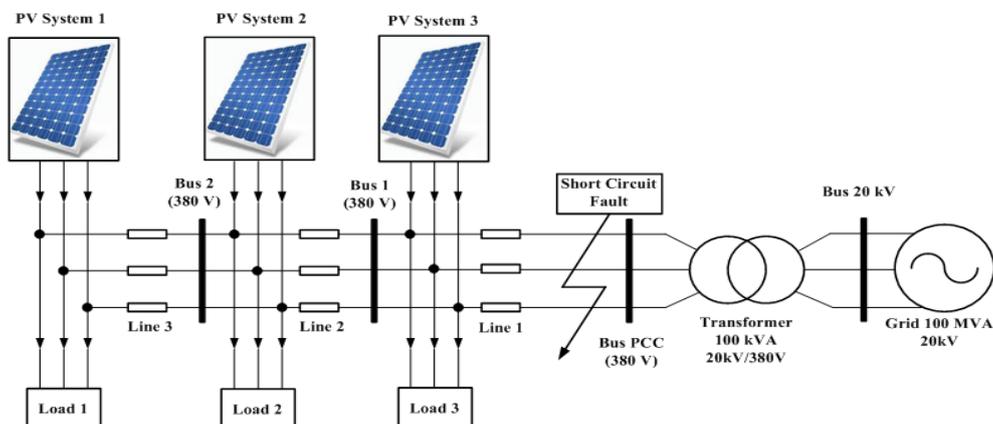


Figure 2. Proposed model of multi PV connected three phase grid under short circuit fault

There are two scenarios of multi PV connected three phase grids under fixed temperature and solar irradiation of 25° C and 1000 W/m<sup>2</sup>, i.e. using MPPT P and O and MPPT Fuzzy methods respectively. The transient state in each of MPPT controllers are indicated by five short-circuit faults, resulting in a total of ten fault scenarios i.e. three phases to ground (3Ph-N), three phases (3Ph), two phases to ground (2Ph-N), two phases (2Ph), and single phase to ground (1Ph-N). The 3ph-N and 3ph are classified as symmetrical faults. Furthermore 2ph-N, 2Ph, and 1Ph-N are classified as non-symmetrical faults. The next process is to determine voltage/current unbalanced, voltage/current harmonics (THD) on each phase, and voltage/current average harmonics on PCC bus of three-phase low voltage grid. The final step is to validate the results referring to the ANSI/IEEE 241-1990 standard about unbalanced voltage and current and IEEE Standard 519-1992 about average grid voltage and current harmonics. Simulation and analysis of this research use Matlab/Simulink. The simulation parameter values of proposed model are shown in Appendix Section.

**2.2. Modelling of PV Array**

Figure 3 shows the equivalent circuit of a solar panel. A solar panel is composed of several PV cells that have series, parallel, or series-parallel external connections [17]. The V-I characteristic of a solar panel is showed in (1):

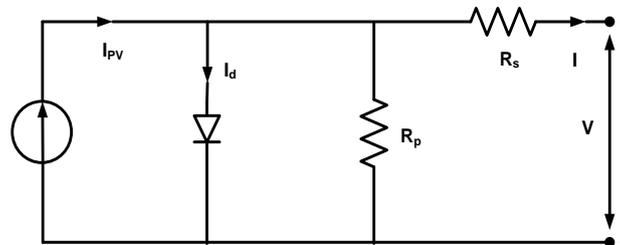


Figure 3. Equivalent circuit of solar panel

$$I = I_{PV} - I_o \left[ \exp \left( \frac{V + R_s I}{aV_t} \right) - 1 \right] - \frac{V + R_s I}{R_p} \tag{1}$$

where  $I_{PV}$  is the photovoltaic current,  $I_o$  is saturated reverse current, 'a' is the ideal diode constant,  $V_t = N_s K T q^{-1}$  is the thermal voltage,  $N_s$  is the number of series cells,  $q$  is the electron charge,  $K$  is the Boltzmann constant,  $T$  is the temperature of p–n junction,  $R_s$  and  $R_p$  are series and parallel equivalent resistance of the solar panels.  $I_{PV}$  has a linear relation with light intensity and also varies with temperature variations.  $I_o$  is dependent on temperature variations.

**2.3. MPPT P and O and MPPT Fuzzy**

The initial research is to determine value of duty cycle (D) with a variable step to control DC/DC boost converter circuit with MPPT P and O. For PV converter, maximum power available is determined by PV cell characteristics, but this value often mismatches with the maximum power point (MPP) of the load. By implementing MPPT in PV systems, MPP can be maintained so that the number and size of PV panels can be reduced or energy yield can be optimized [18]. Because of moving of sun, PV panels angle, and variation of irradiance reaching the panels, energy generated from PV panels are absorbed does not constant over time. When this condition occurs, VI characteristics changes and MPP will move. To overcome these problems, MPPT has been developed. The system includes no moving parts. MPPT search for the maximum power independent based on environmental conditions (following changes in solar radiation and temperature) and maintain the PV terminal voltage remains constant at maximum value. The most used method of MPPT is P and O that algorithm is shown in Figure 4 [13] and its Matlab/Simulink model is presented in Figure 5.

The same procedure for determining MPPT is using FLC. Fuzzy set theory is a new method of controlling the MPPT in obtaining the peak power point. The MPPT is implemented to

obtain MPP operation voltage point faster with less overshoot and also it can minimize voltage fluctuation after MPP has been recognized. It also is capable to enhance power quality problem unbalance current/voltage and current/voltage harmonics. Typical fuzzy based MPPT controller referred to MPPT Fuzzy includes three basic components i.e. fuzzification, inference engine, and defuzzification block as shown in Figure 6 and its Matlab/Simulink presented in Figure 7.

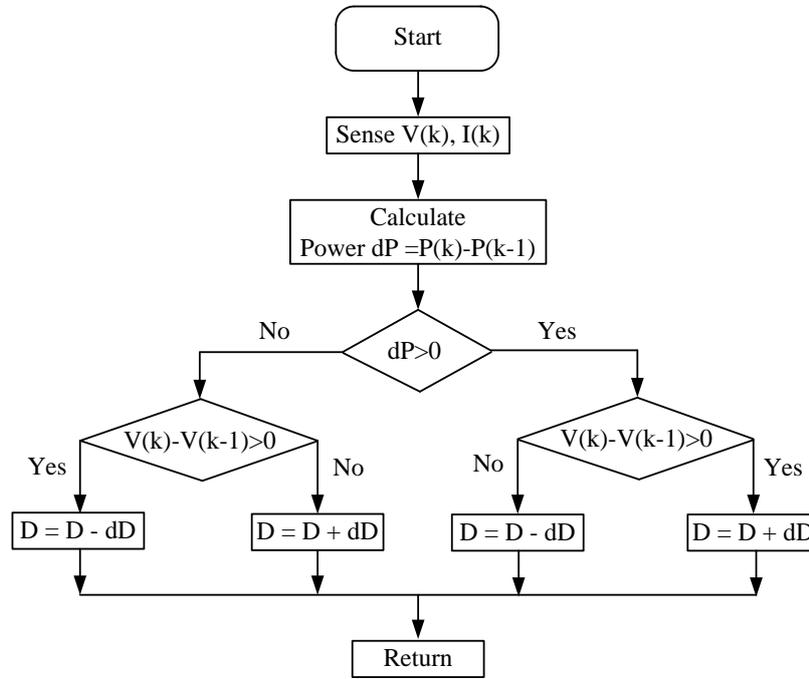


Figure 4. MPPT using P and O algorithm

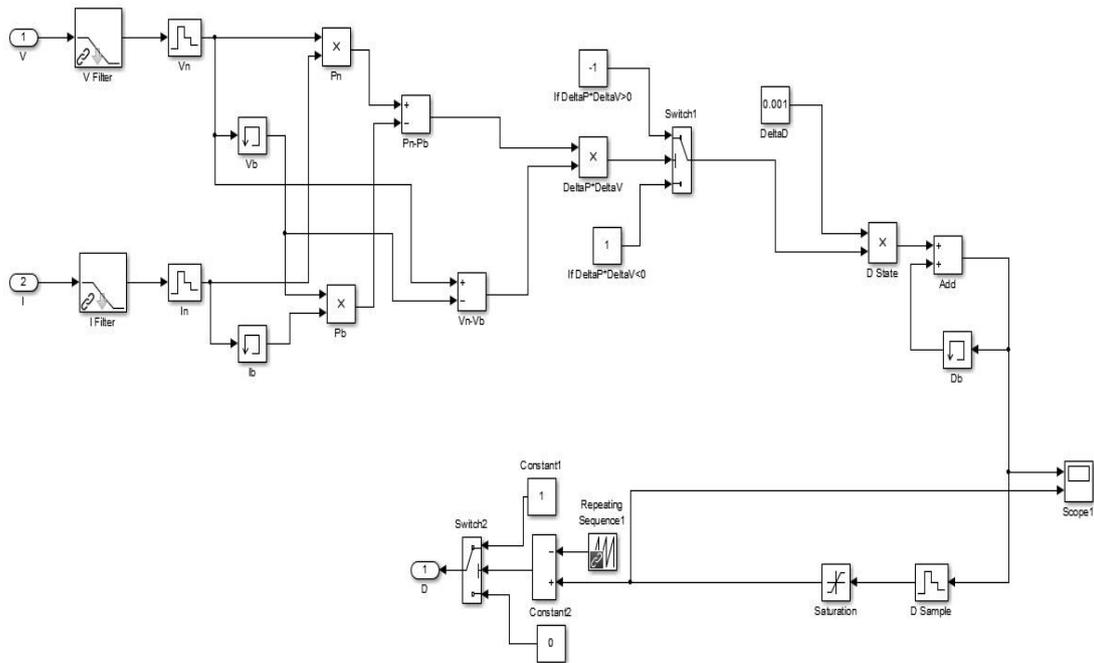


Figure 5. Matlab/Simulink for MPPT P and O

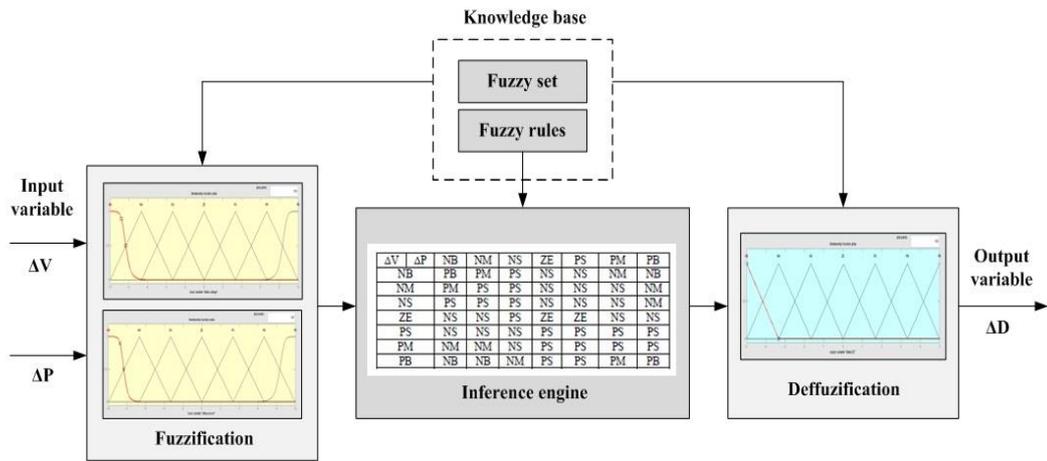


Figure 6. Structure of FLC

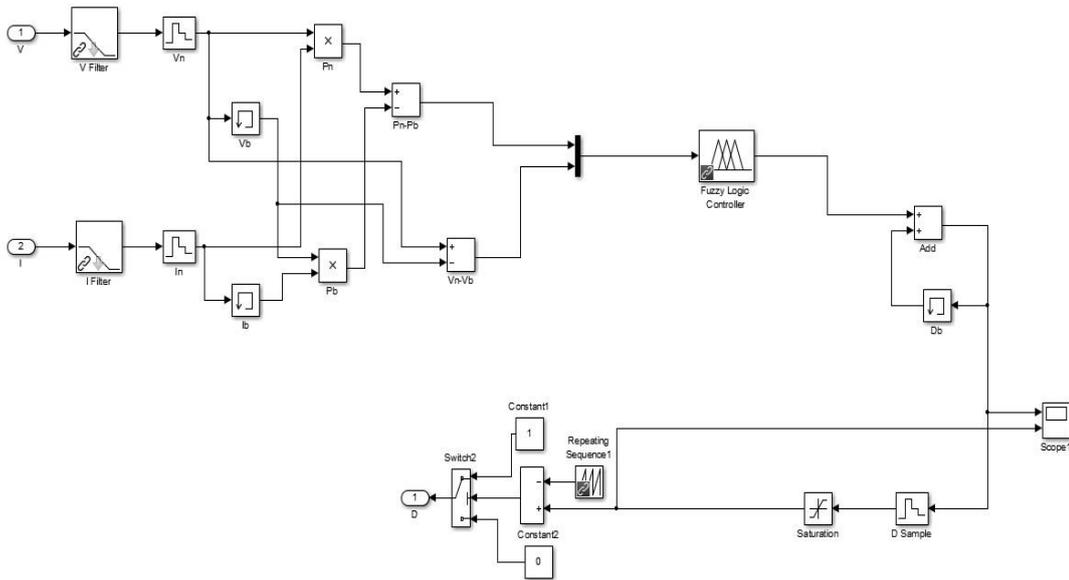


Figure 7. Matlab/Simulink for MPPT Fuzzy

Fuzzy MPPT method is done by determining input variables, namely fuzzy control output power ( $\Delta P$ ) and output voltage ( $\Delta V$ ) PV generator, seven linguistic variables fuzzy sets, fuzzy operating system block (fuzzification, fuzzy rules, and defuzzification), Function  $\Delta P$  and  $\Delta V$  during fuzzification, a table fuzzy rule base, crisp values to determine duty cycle ( $D$ ) in defuzzification phase with variable step to control DC/DC boost converter. Figure 8 shows Matlab/Simulink model for MPPT Fuzzy. During fuzzification phase shown in Figure 7, a number of input variables is calculated and converted into a linguistic variable based on the subset called membership function (MF). To translate value of voltage change and power change in, input fuzzy "change of voltage" and "change of power" is designed to use seven fuzzy variable called PB (Positive Big), PM (Positive Medium), NS (Negative Small), PS (Positive Small) ZE (Zero), NM (Negative Medium), and Negative Big (NB). Voltage change ( $\Delta V$ ) and power changes ( $\Delta P$ ) is a proposed system input variables and output variable FLC is duty cycle change ( $\Delta D$ ). The membership functions i.e. voltage changes, power changes, and duty cycle change, each are shown in Figure 8 into Figure 10.

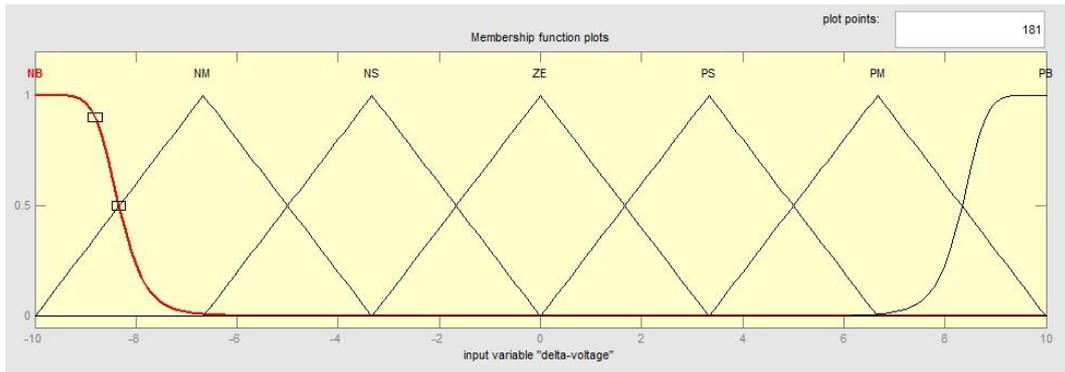


Figure 8. Input voltage change (delta voltage)

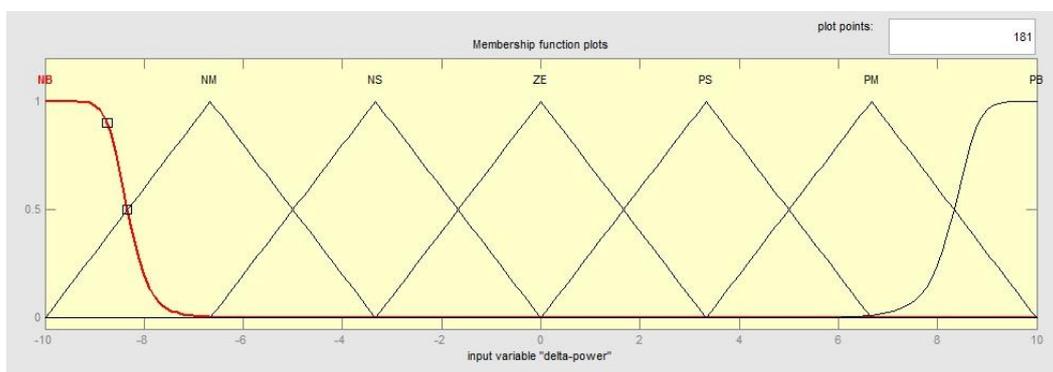


Figure 9. Input power change (delta power)

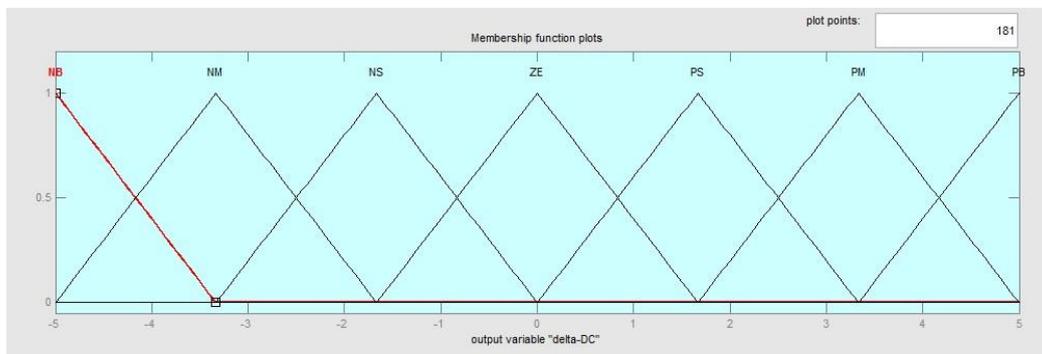


Figure 10. Output duty cycle change (delta D)

The fuzzy inference using a method that relates to a composition Mamdani Max-Min. Fuzzy inference system consists of three parts, namely rule base, database, and reasoning mechanism. After determining  $\Delta V$  and  $\Delta P$ , these value are then converted into linguistic variables and use them as input functions for FLC. The output value is  $\Delta D$  is generated using block inference and fuzzy rules as shown in Table 1. Finally defuzzification block operates to change value of  $\Delta D$  is raised from linguistic variables into numeric variables back. Numeric variables that become inputs signal for the IGBT switch of DC/DC boost converter to be able to determine MPPT for each generation PV accurately at the same time also improve power quality as a result of integration of multi PV to low voltage three phase grid under short circuit.

Table 1. Fuzzy Rules

$\Delta V$	$\Delta P$	NB	NM	NS	ZE	PS	PM	PB
NB		PB	PM	PS	NS	NS	NM	NB
NM		PM	PS	PS	NS	NS	NS	NM
NS		PS	PS	PS	NS	NS	NS	NM
ZE		NS	NS	PS	ZE	ZE	NS	NS
PS		NS	NS	NS	PS	PS	PS	PS
PM		NM	NM	NS	PS	PS	PS	PS
PB		NB	NB	NM	PS	PS	PM	PB

**2.4. Voltage and Current Harmonics/Unbalance**

Generally, current and voltage waveforms are pure sinusoidal. One problem that occurs is non sinusoidal or distorted current and voltage waves generated by harmonics in power system [11]. Harmonic is distorted periodic steady state wave caused by the interaction between the shapes of a sine wave at the fundamental frequency system with another wave component which is an integer multiples frequency of fundamental frequency. The most common harmonic index, which relates to voltage waveform is THD (2), which is defined as the root mean square (rms) of harmonics expressed as a percentage of fundamental component as showed in [19]. Second harmonic index is current THD means the ratio of rms harmonic current value to rms fundamental current which expressed in (3) [11].

$$THD_V = \frac{\sqrt{\sum_{n=2}^N V_n^2}}{V_1} \times 100 \% \tag{2}$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^N I_n^2}}{I_1} \times 100 \% \tag{3}$$

$$V(\%) = \frac{|V_{average} - V_{a,b,c \min \text{ or } \max}|}{V_{average}} \times 100 \% \tag{4}$$

Where  $V_n$  and  $I_n$  (the rms voltage and current at harmonic  $n$ ),  $V_1$  and  $I_1$  (the fundamental rms voltage and current),  $N$  (the maximum harmonic order to be considered). The allowable maximum THD value for each country is different depending on the standard used. THD standards most often used in electric power system is IEEE 519-1992. There are two criteria used in analysis of harmonics distortion i.e. voltage distortion and current distortion limit [20]. The value of unbalance voltage use (8) is based ANSI/IEEE 241-1990 is showed in (4) [21]. By using (4), value of unbalance voltage expressed in percent (%) and is defined as follows;  $V_{average}$  is the average value of maximum voltage on phase a, b, c, in volt.  $V_{a,b,c \min}$  is minimum voltage on phase a, b, c in volt,  $V_{a,b,c \max}$  is maximum voltage on phase a, b, c in volt. By the same way, then unbalance current in % can be calculated by replacing voltage into current magnitude.

**3. Results and Analysis**

This research is started by determining the maximum and minimum of grid current in each phase, unbalanced current using (4), current THD on each phase (3), and average THD of three phase current grids on PCC bus using MPPT P and O/MPPT Fuzzy. By using the same procedure then obtained unbalanced voltage using (4), voltage THD on each phase using (2), and average voltage THD. Table 2 shows unbalanced current, THD grid current, and average THD of grid current of multi PV connected on a three phase low voltage grid using MPPT P and O/MPPT Fuzzy. Because, there are five short-circuit faults then there are three fault durations i.e. before, during (transient), and after fault phase with time durations are 0-0.02 sec, 0.02-0.04 sec, and 0.04-0.06 sec respectively. The simulation result of unbalanced current/voltage and average THD current/voltage is also presented as verification under five short circuit faults. The results analysis is conducted only on short circuit fault during transient phase. Figure 11 shows current waveform of multi PV connected to three phase grid on a PCC bus using MPPT P and O/MPPT Fuzzy under normal condition, 3Ph-N, 2Ph-N, and 1Ph-N fault.

Table 3 shows unbalanced voltage, THD grid voltage, and average THD of grid voltage of multi PV connected on a three phase low voltage grid using MPPT P and O/ MPPT Fuzzy.

Table 2. Unbalance Current and Average Current Harmonics under Transient Phase

No.	Fault Types	Phase Current (V)			Unba Current (%)	THD <sub>i</sub> (%)			Avg THD <sub>i</sub> (%)
		A	B	C		A	B	C	
MPPT P and O Method									
1	Normal	10.61	10.74	10.69	0.562	2.65	3.22	3.40	3,090
2	3Ph-N	1331	1359	1296	2.283	4.41	2.05	2.38	2.947
3	3Ph	1331	1359	1296	2.283	4.41	2.05	2.38	2.947
4	2Ph-N	1336	1350	7.671	50.353	4.70	1.76	3.91	3.457
5	2Ph	1179	1179	10.32	49.347	3.67	3.67	3.33	3.557
6	1Ph-N	1132	9.451	9.482	195.065	4.96	3.27	4.06	4.097
MPPT Fuzzy Method									
1	Normal	10.72	10.76	10.80	0.372	3.32	3.76	4.28	3.787
2	3Ph-N	1331	1359	1296	2.283	4.41	2.05	2.38	2.947
3	3Ph	1331	1359	1296	2.283	4.41	2.05	2.38	2.947
4	2Ph-N	1336	1350	7.475	50.364	4.70	1.76	6.0	4.154
5	2Ph	1179	1179	10.09	49.361	3.69	3.66	5.10	4.150
6	1Ph-N	1332	9.203	9.319	195.886	4.97	4.88	5.28	5.044

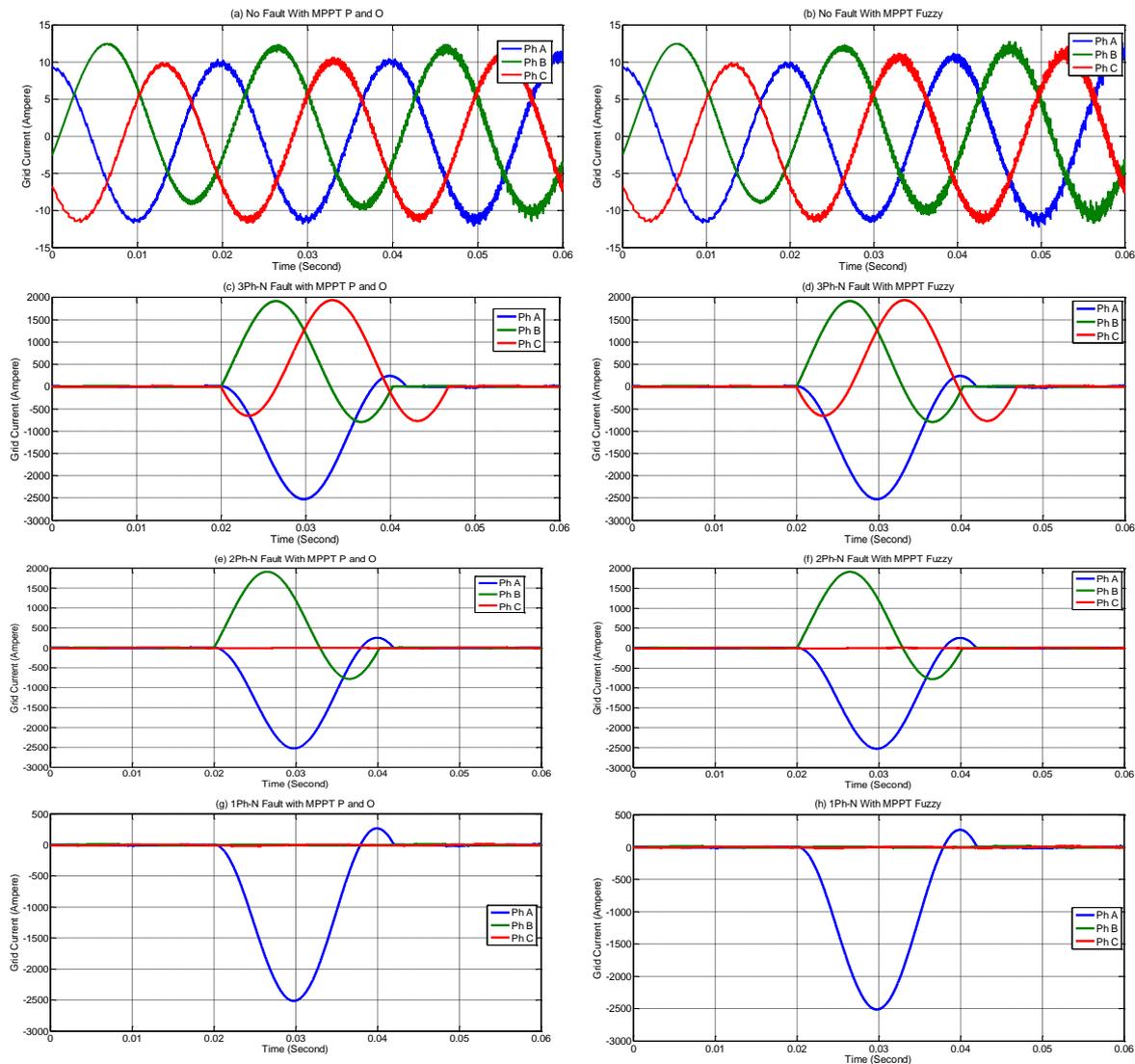


Figure 11. Current waveform of multi PV connected to a three phase grid on PCC bus

Table 3. Unbalance Voltage and Average Voltage Harmonics under Transient Phase

No.	Fault Types	Phase Voltage (V)			Unba Voltage (%)	THD <sub>v</sub> (%)			Avg THD <sub>v</sub> (%)
		A	B	C		A	B	C	
MPPT P and O Method									
1	Normal	308.8	308.7	307.8	0	6.74	7.06	7.14	6.980
2	3 Ph-N	1.332	1.350	1.307	1.523	6.50	179.32	189.46	125.094
3	3 Ph	1.347	1.325	1.318	1.279	275.94	336.34	341.31	317.864
4	2 Ph-N	2.242	2.268	308.4	195.677	5.36	106.86	7.83	39.017
5	2 Ph	155.0	152.7	307.8	50.025	7.96	8.09	7.72	7.924
6	1Ph-N	2.658	308.1	308.1	49.356	5.48	7.56	7.88	6.974
MPPT Fuzzy Method									
1	Normal	307.7	307.7	307.7	0	8.23	9.74	9.79	9.254
2	3 Ph-N	1.332	1.351	1.306	1.605	5.38	172.84	181.97	120.064
3	3 Ph	1.339	1.343	1.307	1.003	223.47	283.53	294.43	267.144
4	2 Ph-N	2.242	2.269	308.4	195.676	4.90	102.82	11.16	39.627
5	2 Ph	155.0	152.7	307.8	50.025	10.12	10.28	9.98	10.127
6	1Ph-N	2.657	308.1	308.0	49.381	5.22	9.77	10.63	8,570

Figure 12 shows grid current harmonics spectra of phase A during transient phase due to the multi PV connected to three phase grid on PCC bus using MPPT P and O and MPPT Fuzzy method under 1Ph-N fault.

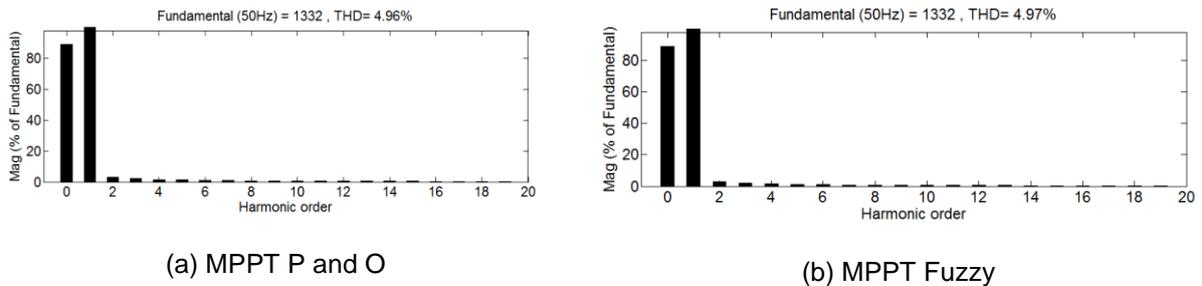
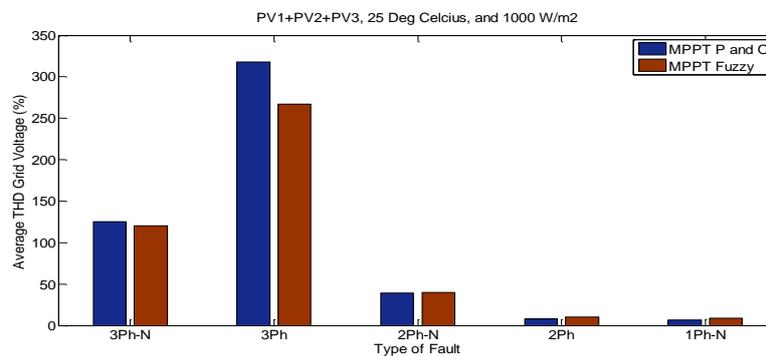


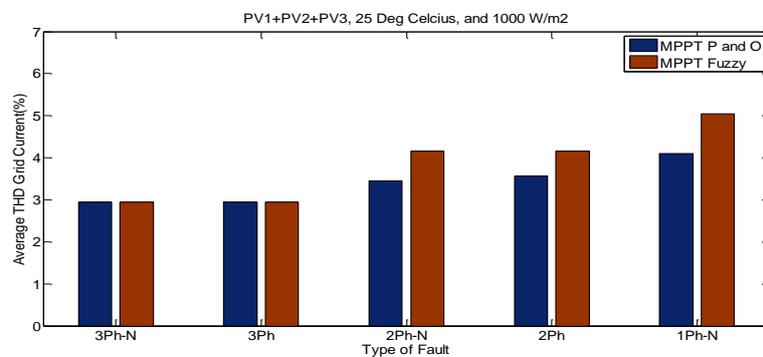
Figure 12. Current harmonics spectra of phase A under 1Ph-N fault

Table 2 presents that under normal condition, phase current of multi PV (PV1+PV2 + PV3) using MPPT P and O in transient phase are 10.61 A, 10.74 A, 10.69 A and able to result an unbalanced current of 0.562%. In short circuit faults, the highest unbalanced current of transient phase is generated by 1Ph-N fault of 195.886%. The 3Ph-N and 3Ph fault on transient phase are able equally produce an unbalanced current of 2,283%. The implementation of MPPT Fuzzy method under normal condition is able to generate an unbalanced current of 0.372%. If using MPPT Fuzzy under fault on transient phase, the highest unbalanced current is generated by 1Ph-N faults of 195.886%. At the same condition the smallest unbalanced current is equally generated by 3Ph-N and 3Ph fault of 2.282%. In non-symmetrical fault, the use of MPPT P and O is able to result an unbalanced current of transient phase slightly lower than MPPT Fuzzy. While in symmetrical faults, MPPT P and O/MPPT Fuzzy method for controlling of output power of multi PV gives same unbalanced current of transient phase of 2,283%. In normal condition, by using both MPPT P and O and MPPT Fuzzy method, the average THD current on transient phase are 3.090% and 3.787%, respectively. When using MPPT P and O, the highest average THD current is generated by 1Ph-N fault of 4,097%. In the same method, the smallest average THD voltage is equally generated by 3Ph-N and 3Ph of 2,947%. If using Fuzzy MPPT, the highest average THD current is generated by 1Ph-N fault of 5.044%. In the same method, the smallest average THD current is equally generated by 3Ph-N and 3Ph of 2,947%. In the symmetrical faults, both MPPT P and O and MPPT Fuzzy method is able equally result an average THD current during transient phase of 2,947%. In non-symmetrical fault, MPPT P and O is able to result an average THD current slightly smaller than MPPT Fuzzy method.

Table 3 presents that under normal condition, multi PV using MPPT P and O under transient phase is able to result an unbalanced voltage of 0%. In the short circuit faults, the highest unbalanced voltage during transient phase is generated by a 2Ph-N fault of 195.677% volt. The 3Ph fault during transient phase is able to result the smallest unbalanced voltage of 1.279%. MPPT Fuzzy under normal condition is also able to result an unbalanced voltage of 0%. When using the MPPT Fuzzy under short-circuit fault during transient phase, the highest unbalanced voltage is generated by a 2Ph-N fault of 195.676% and the lowest unbalanced voltage is generated by 3Ph fault of 1.003%. In non-symmetrical faults, the implementation of MPPT P and O and MPPT Fuzzy method to control output power of multi PV produces nominal unbalanced voltage during transient phase results a close the same value. While in symmetrical fault, MPPT P and O and MPPT Fuzzy are able to result different unbalance voltage on transient phase. During 3Ph-N fault on transient phase, MPPT P and O method is able to result an unbalanced transient phase voltage of 1.523% slightly lower than MPPT Fuzzy of 1.605%. However during 3Ph fault on transient phase, MPPT Fuzzy is able to produce an unbalanced voltage of 1.003% slightly lower than MPPT P and O of 1.279%. In normal condition, the use of both MPPT P and O and MPPT Fuzzy method are able to result THD average voltages i.e. 6.980% and 9.254%, respectively. If using MPPT P and O, the largest average THD voltage is generated by a 3Ph fault of 317.864%. By using the same method, the lowest average THD voltage is produced by 1Ph-N fault of 6.974%. If using Fuzzy MPPT, the largest average THD voltage is also generated by a 3Ph fault of 267.144%. By using the same method, the lowest average THD voltage is generated by 1Ph-N fault of 8.570%. During symmetrical fault on transient phase, MPPT Fuzzy is able to result an average THD voltage smaller than MPPT P and O. Otherwise during non-symmetrical fault on transient phase, MPPT P and O is able to result an average THD voltage slightly lower than MPPT Fuzzy. Performance of average voltage is shown as Figure 13 (a) and current harmonic during transient phase is shown as Figure 13 (b).



(a) Average THD voltage



(b) Average THD current

Figure 13. Performance of (a) average voltage and (b) current harmonic during transient phase

Figure 13 (a) shows that on symmetrical faults during transient phase (3Ph-N and 3Ph), MPPT Fuzzy is able to result an average THD voltage smaller than MPPT P and O method. Otherwise on non-symmetrical faults during transient phase (2Ph-N, 2Ph, and 1Ph-N), MPPT P and O is able to result an average THD voltage slightly smaller than MPPT Fuzzy. Figure 13(b) shows that on symmetrical faults during transient phase, MPPT Fuzzy and MPPT P and O method are able to result the same average THD current. Furthermore on non-symmetrical faults during transient phase, MPPT P and O is able to result an average THD current slightly smaller than MPPT Fuzzy. The MPPT P and O and the MPPT Fuzzy on all short circuit fault during transient phase (3Ph-N, 3Ph, 2Ph-N, 2Ph, and 1Ph-N) are able to result smaller current average THD current significantly depend on average THD voltage.

#### 4. Conclusion

Comparative performance of multi PVs connected grid under short circuit fault during transient phase to power quality using MPPT P and O/MPPT Fuzzy has been presented. During transient phase, non-symmetrical faults (2Ph-N, 2Ph, and 1Ph-N) is able to generate unbalance current/voltage greater depend on symmetrical faults (3Ph-N and 3Ph). On symmetrical faults, MPPT Fuzzy is able to result an average THD voltage/THD current smaller than MPPT P and O. Otherwise on non-symmetrical faults, MPPT P and O is able to result an average THD voltage/THD current slightly smaller than MPPT Fuzzy. The MPPT P and O/MPPT Fuzzy method on all short circuit faults during transient phase are able to result smaller current average THD than average THD voltage significantly. Furthermore the nominal of average THD current using both methods has also met THD limit prescribed in IEEE 519.

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## Appendix

PV generator 1, 2, and 3: active power=100 kW, temperature=25<sup>0</sup> C, irradiance=1000 W/m<sup>2</sup>; Three phase grid: short circuit power=100 MVA, voltage=380 volt (L-L), frequency=50 Hz; Power transformer: rated power=100 kVA, frequency=50 Hz, voltage 380 Volt/20 kV (L-L), two winding type; Load 1, 2, and 3: active power=20 kW, voltage=380 volt (L-L), frequency=50 Hz; Low Voltage Lines 1, 2, and 3: resistance R=0,1273 Ohm/km, inductance L=93,37 mH/km, capacitance C=1,274 μF/km; Length of Low Voltage Lines: Line 1, Line 2, Line 3=1 km; DC link capasitor: capacitance= 2000 μF, frequency = 4 kHz; PWM generator for DC/AC inverter: Sampling time= 5x10<sup>-6</sup> Second; Fuzzy inference system=mamdani method; Fuzzy model composition=max-min; Input membership function: delta voltage=gbellmf, trimf, delta power: gbellmf, trimf; Output membership function: delta duty cycle=trimf.