

An Advanced Fuzzy Design of Active and Reactive Power Control for Large-Scale Grid-Connected Photovoltaic Systems Using Multilevel Converters

¹. R.R.MANISRI, ². N.P.V.L.R.C.SEKHAR

¹. P.G.Scholar, Dept of EEE, Eluru College of engineering & technology, Duggirala (v), Eluru

². ASSOCIATE PROFESSOR, Dept of EEE, Eluru College of engineering & technology, Duggirala (v), Eluru

Abstract— Solar Cells supplemented with energy storage system are considered as the promising source of alternative energy for portable, transportation and distributed generation applications. High power density of the super capacitor and high energy storage capability of the battery make them ideal choice as the energy storage system. The integration of these three power sources however, poses several difficulties for control system designers. In this paper, it is shown that a supervisory fuzzy logic based control system can well handle the situation associated with the integration. The higher multi level supervisory controller monitors the load demand, power availability of the solar cell and state of the charge of the battery/super capacitor and decides the operating condition of the system. The operating parameters are sent to the lower level power electronics controllers. A unidirectional DC/DC converter and two bidirectional DC/DC converters are designed for the power electronics interface. All the simulations are carried out in the matlab/simulink environment. The supervisory controller is implemented using state flow and fuzzy logic toolbox of matlab.

KEYWORDS: Solar Cells, Photovoltaic System, Active and Reactive Power, multilevel converters, maximum power point tracking, H-BRIDGES INVERTER

I. INTRODUCTION

GLOBAL energy crises and environmental concerns [1]–[3] from conventional fossil fuels have attracted more and more renewable energy developments in the worldwide.

Among of these renewable energy, solar energy is much easier to be harvested, converted, and delivered to grid by a variety of power converters [4]–[14]. In particular, large-scale grid-connected photovoltaic (PV) systems play a major role to achieve PV grid parity and have been put forward in high penetration renewable energy systems [15]. As one type of modular multilevel converters, cascaded multilevel converters share many merits of modular multilevel converters, e.g., lower electromagnetic interference, low device rating, improved harmonic spectra, modularity, etc.,

but also is very promising for the large-scale PV system due to its unique advantages such as independent maximum power point tracking (MPPT) for segmented PV arrays, high ac voltage capability, etc. [11]–[14].

However, cascaded multilevel converters in PV systems are different from their some successful application such as medium voltage motor drive, static synchronous compensator (STATCOM), harmonic compensator, solid state transformer, which are connected with symmetrical segmented dc sources [16]–[22]. PV systems with cascaded multilevel converters have to face tough challenges considering solar power variability and mismatch of maximum power point from each converter module due to manufacturing tolerances, partial shading, dirt, thermal gradients, etc. In a cascaded PV system, the total ac output voltage is synthesized by the output voltage from each converter module in one phase leg, which must fulfill grid codes or requirements. Because same grid current flows through ac side of each converter module, active power mismatch will result in unsymmetrical ac output voltage of these modules [14]. The converter module with higher active power generation will carry more portion of the whole ac output voltage, which may cause overmodulation and degrade power quality if proper control system is not embedded into the cascaded PV system. Several control strategies have been proposed for the cascaded PV system with direct connection between individual inverter module and segmented PV arrays [23]–[27]. But they did not consider the fact that PV arrays cannot be directly connected to the individual inverter module in high-voltage large-scale PV system application due to the PV insulation and leakage current issues. Even if there are low-frequency medium-voltage transformers between the PV converters and grid, there are still complicated ground leakage current loops among the PV converter modules [28]. Therefore, those methods in [23]–[27] are not qualified for a practical large-scale grid-connected cascaded PV system. Moreover, reactive power compensation was not achieved in [23]–[26], which largely limits the functions of the

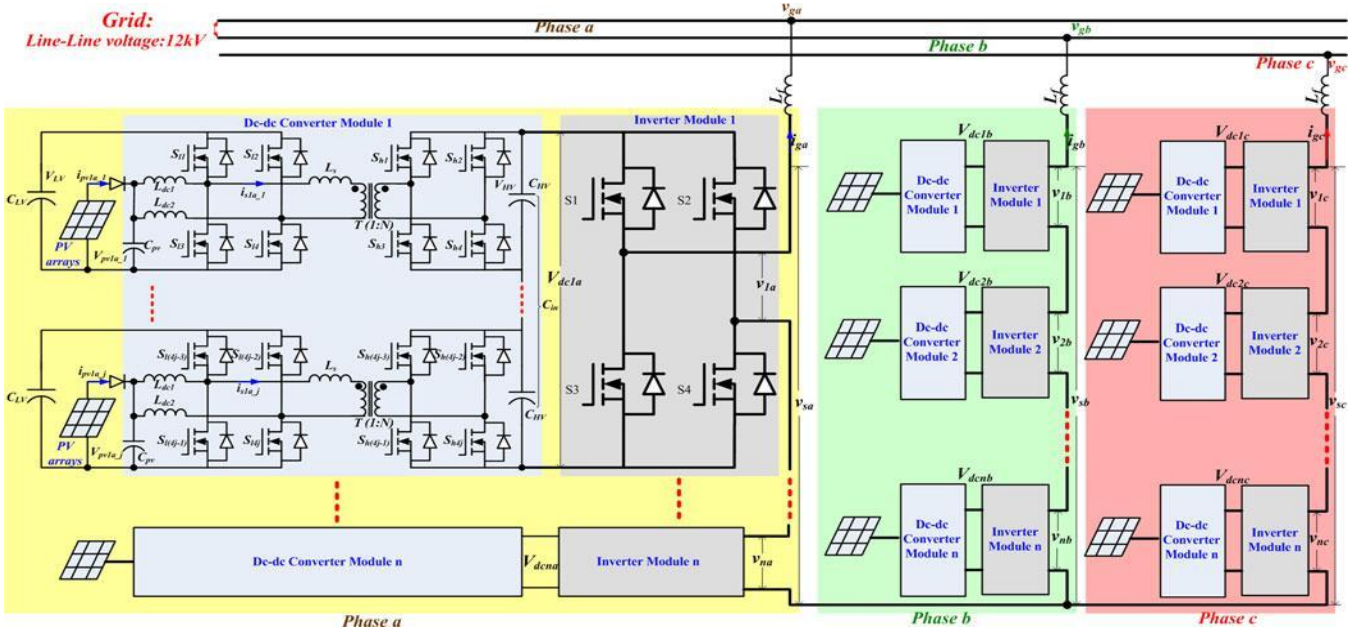


Fig. 1. Proposed grid-connected PV system with cascaded multilevel converters at 3 MW.

cascaded PV system to provide ancillary services. Proper reactive power compensation can significantly improve the system reliability, and in the meantime help the MPPT implementation for the cascaded module under unsymmetrical condition as well as comply with the system voltage requirement simultaneously [29]. A reactive and active power control strategy has been applied in cascaded PV system with isolated dc-dc converters in [30] and [31]. If symmetrical active power comes from each module, active and reactive power can be equally distributed into these modules under traditional power control in [30] and [31]. However, if unsymmetrical active power is generated from these modules, this control strategy will not be able to achieve decoupled active and reactive power control. Reactive power change is along with the active power change at the same direction, which may aggravate output voltage overmodulation during unsymmetrical active power outputs from segmented PV arrays.

In order to solve the aforementioned issues, this paper proposes a large-scale grid-connected cascaded PV system including current-fed dual-active-bridge (CF-DAB) dc-dc converters and cascaded multilevel inverters as shown in Fig. 1. A decouple active and reactive power control system is developed to improve the system operation performance. Reactive power from each PV converter module is synchronously controlled to reduce the overmodulation of PV converter output voltage caused by unsymmetrical active power from PV arrays. In particular, the proposed PV system allows a large low-frequency dc voltage ripple for each PV converter module, which will not affect MPPT achieved by CF-DAB dc-dc converters. As a result, film capacitors can be applied to replace the conventional electrolytic capacitors, thereby enhancing system lifetime.

This paper is organized as follows: a two-stage large-scale grid-connected cascaded PV system topology and correspond-

ing power flow distribution are first introduced in Section II. A vector method is derived to help illustrate the active and reactive power distribution principle between the cascaded PV inverter modules. In Section III, a comprehensive control system with CF-DAB dc-dc converters control and cascaded multilevel inverter control is developed.

The decoupled active and reactive power control including active and reactive components extraction, voltage distribution and synthesis, is executed in multilevel inverter control system to achieve independent active and reactive power distribution. Fuzzy logic can be explained in section IV. A three-phase 3-MW/12-kV PV system including 12 cascaded PV inverter modules with the proposed decoupled active and reactive power control strategy is modeled in MATLAB/Simulink platform, simulation results are shown in section V and finally conclusions are presented in section VI.

II. SYSTEM STRUCTURE AND POWER FLOW ANALYSIS

A. System structure

The proposed large-scale grid-connected PV system is presented in Fig. 1, which demonstrates a three-phase two-stage power conversion system. It includes n cascaded multilevel inverter modules for each phase, where each inverter module is connected to j cascaded CF-DAB dc-dc converter modules with high voltage insulation [32]. This configuration features many impressive advantages comparing with traditional PV systems with line-frequency transformer. The cascaded multilevel inverters are directly connected to the grid without big line-frequency transformer, and the synthesized output voltage from cascaded modules facilitates to be extended to meet high grid voltage

TABLE I
SYSTEM CIRCUIT PARAMETERS IN SIMULATION

Parameters		Symbol	Value
PV inverter modules in each phase	Number	n	4
	DC Capacitor voltage	$V_{dcki} (k=1,2,...,n; i=a,b,c)$	3000 V
	DC Capacitor size	C_{in}	400 μ F
	Filter inductor	L_f	0.8 mH
	Switching frequency	$f_{sw,AC}$	5 kHz
CF-DAB DC-DC converter module	Number	j	5
	Capacitor voltage in low voltage capacitor	V_{LV}	300V
	Capacitor voltage in low voltage capacitor	V_{HV}	600V
	Transformer turn ratio	N	2
	PV arrays output voltage	$V_{pvki,r} (k=1,2,...,n; i=a,b,c; r=1,2,...,j)$	100 V - 200 V
	Leakage inductor	L_s	2.5 μ H
	DC inductor value	L_{dc1}, L_{dc2}	12.5 mH
	Capacitor in high voltage side	C_{HV}	2 mF
	Capacitor in low voltage side	C_{LV}	300 μ F
	PV arrays output capacitor	C_{pv}	100 μ F
	Switching frequency	$f_{sw,DC}$	50 kHz
Grid (three phase)	Rated real power	P_g	3 MW
	Rated reactive power	Q_g	1.5 MVAR
	Rated RMS line-line voltage	V_{gl-L}	12 kV

requirement due to the modular structure. Each dc–dc converter module is interfaced with segmented PV arrays and therefore the independent MPPT can be achieved to harvest more solar energy. Moreover, it is immune to the double-line-frequency power ripple propagation into PV arrays. Particularly, the ground leakage current and PV insulation issues are effectively suppressed. In addition, flexible control strategies are able to be explored and applied in this topology owing to more control variables and control degree-of-freedom. Although there is no accurate number about the cost benefits comparing with the traditional PV system with line-frequency transformer, it is obvious that the proposed PV system will have lower cost due to high power density and modular structure, which will significantly reduce the cost of the power platform using to install the PV system. This paper is focused on active and reactive power distribution control of the cascaded multilevel inverters in the proposed PV system. The detailed dc–dc converter design has been provided in [32] and will not be repeated in this paper. The selected application is a 3-MW/12-kV PV system in this paper. The n is selected to be 4 considering the tradeoff among the cost, lifetime, passive components, switching devices and frequency selection, and power quality. As a result, power rating of each inverter module is 250 kW. The average dc voltage of each inverter module is 3000 V based on the requirement of inverter output voltage, power devices as well as power quality. The second-order voltage ripple on the dc side is allowed to 20% even higher. Hence, film capacitor with 400 μ F, C_{in} , is eligible to improve the system lifetime. In addition, the modular structure enables the high-voltage high-frequency SiC power devices for the HVHP PV application. The switching frequency for each power device is 5 kHz. Due to the phase-shift carrier-based phase-width modulation (PWM) control, the PV inverter will generate nine level output voltage and the equivalent output PWM frequency is 40 kHz for each phase. The current ripple of ac inductor is selected to be less than 20% of the rated output current. Therefore, the ac inductor with 0.8 mH, L_f , is acted as

the filter. In each dc–dc converter module, L_{dc1} and L_{dc2} are dc inductors, and L_s is leakage inductor. C_{pv} is high-frequency filter capacitor paralleled with PV arrays. High-frequency transformer with turn ration N is connected between low-voltage side (LVS) converter and high-voltage side (HVS) converter. C_{LV} are LVS dc capacitor and C_{HV} are HVS dc capacitor. The detailed parameters have been provided in Table I.

B. Power Flow Analysis

In the cascaded PV system, power distribution between these modules is primarily dominated by their respective ac output voltage because the same grid current flows through these modules in each phase as shown in Fig. 1. Vector diagrams are derived in Fig. 2 to demonstrate the principle of power distribution between four PV inverter modules in phase a . The same analysis can be applied for phases b and c . Considering the relative stability of the grid voltage, v_{ga} is used for the synchronous signal. The α -axis is in phase with grid voltage and the β -axis lags the α -axis by 90° as shown in Fig. 2(a). The d -axis is aligned with the grid voltage by the phase-locked loop (PLL) control [8] and the q -axis lags the d -axis by 90° . The components of grid voltage in $\alpha\beta$ stationary frame and dq rotating frame can be written in (1) and (2), respectively

$$\begin{cases} v_{ga,\alpha} = v_{ga} \sin \omega t \\ v_{ga,\beta} = -v_{ga} \cos \omega t \end{cases} \quad 1$$

$$\begin{bmatrix} v_{ga,d} \\ v_{ga,q} \end{bmatrix} = \begin{bmatrix} \sin \omega t & -\cos \omega t \\ \cos \omega t & \sin \omega t \end{bmatrix} \begin{bmatrix} v_{ga,\alpha} \\ v_{ga,\beta} \end{bmatrix} \quad 2$$

The grid current is relatively stable to the grid voltage in steady state. Therefore, the new d -axis (d^1) can be aligned with the grid current. It is obvious that the d^1 -axis component of the inverter output voltage $v_{sa,d}$ determines the active power

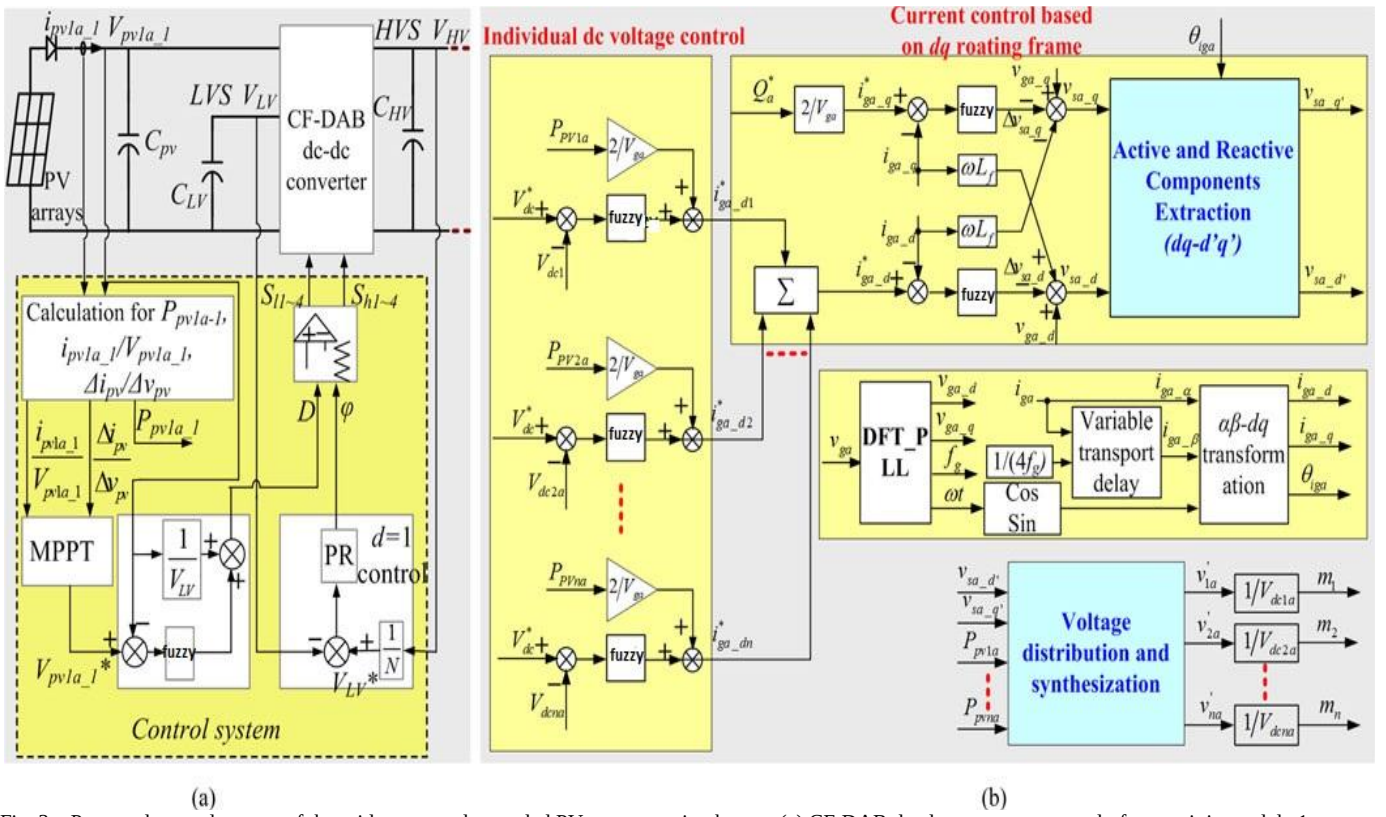


Fig. 3. Proposed control system of the grid-connected cascaded PV converters in phase a. (a) CF-DAB dc-dc converters control of one unit in module 1. (b) Cascaded multilevel inverters control.

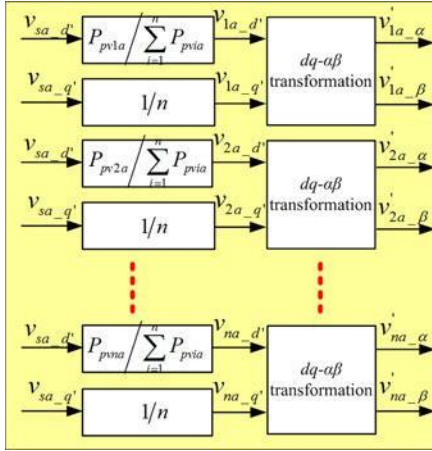


Fig. 4. Proposed voltage distribution and synthesis of the cascaded PV inverters in phase a.

Therefore, θ_{iga} can be obtained based on the dq components of grid current i_{ga-d} and i_{ga-q} by the $\alpha\beta$ - dq transformation as follows:

$$\begin{bmatrix} i_{ga-d} \\ i_{ga-q} \end{bmatrix} = \begin{bmatrix} \sin \omega t & -\cos \omega t \\ \cos \omega t & \sin \omega t \end{bmatrix} \begin{bmatrix} i_{ga-\alpha} \\ i_{ga-\beta} \end{bmatrix} \quad (k=1,2,\dots,n) \quad (3)$$

Where $\theta_{iga} = \tan^{-1}(i_{ga-q}/i_{ga-d})$ is the grid current angle.

Accordingly the desired V_{sa-d} and V_{sa-q} can be derived by

$$\begin{bmatrix} v_{sa-d} \\ v_{sa-q} \end{bmatrix} = \begin{bmatrix} \cos \theta_{iga} & \sin \theta_{iga} \\ -\sin \theta_{iga} & \cos \theta_{iga} \end{bmatrix} \begin{bmatrix} v_{sa-d} \\ v_{sa-q} \end{bmatrix} \quad (4)$$

2) Voltage Distribution And Synthesis: The voltage and distribution and synthesis module as shown in Fig4 is

developed to perform the active and reactive power distribution for each module. The active components V_{ka-d}^1 ($k=1,2,\dots,n$) of each module output is determined by their respective active power contribution which the ratio is $P_{pvka} / \sum_{i=1}^n P_{pvia}$ ($k = 1,2,\dots,n$). The reactive power output from each module is controlled to be the same in order to mitigate output voltage overmodulation caused by unsymmetrical active power from segmented PV arrays[29]. Hence the corresponding reactive components V_{ka-q}^1 ($k=1,2,\dots,n$) are distributed with the same ratio $1/n$ accordingly the output voltage of each module can be expressed by.

$$\begin{bmatrix} v_{ka-\alpha}^1 \\ v_{ka-\beta}^1 \end{bmatrix} = \begin{bmatrix} \sin(\omega t + \theta_{iga}) & \cos(\omega t + \theta_{iga}) \\ -\cos(\omega t + \theta_{iga}) & \sin(\omega t + \theta_{iga}) \end{bmatrix} \begin{bmatrix} v_{ka-d}^1 \\ v_{ka-q}^1 \end{bmatrix}$$

Where $v_{ka}^1 = v_{ka-\alpha}^1$ is the desired output voltage of each module $v_{ka-\beta}^1$ is the imaginary quadrature signal with v_{ka}^1 and can be ignored in this control system.

Therefore the modulation index of respective output voltage can be obtained by $m_k = V_{ka}^1 / V_{dcka}$ shown in fig 3(b). As a result the active and reactive power can be properly distributed in each module which achieves the MPPT and augments the security and stability of the cascaded PV system operation simultaneously.

IV. Proposed Technique

Fuzzy logic controller

A fuzzy logic controller has four main components as shown in Figure 5: fuzzification interface, inference mechanism, rule base and defuzzification interface. FLCs are complex, nonlinear controllers. Therefore it's difficult to predict how the rise time, settling time or steady state error is affected when controller parameters or control rules are changed.

Implementation of an FLC requires the choice of four key factors: number of fuzzy sets that constitute linguistic variables, mapping of the measurements onto the support sets, control protocol that determines the controller behaviour and shape of membership functions. Thus, FLCs can be tuned not just by adjusting controller parameters but also by changing control rules, membership functions etc. The main advantages of adaptive fuzzy control over non adaptive fuzzy control are: better performance is usually achieved because the adaptive fuzzy controller can adjust itself to the changing environment, and less information about the plant is required because the adaptation law can help to learn the dynamics of the plant during real time operation. However, these approaches still have some problems. The adaptive control scheme proposed by Wang guarantees the uniform boundedness of all signals of the control system but it is applicable only to single-input single-output system. In many applications, the structure of the model of the plant may be known, but its parameters may be unknown and/or change with time. Recently, the concept of incorporating fuzzy logic control into the model reference adaptive control has grown into an interesting research topic. Moreover, it can eliminate multiple harmonics in the circulating current with a single repetitive controller. However, the repetitive controller and the FUZZY controller are paralleled. Such an arrangement imposes unnecessary limitation on the FUZZY controller design and also complicates the repetitive controller design. This paper proposes a different repetitive-plus-FUZZY control scheme. The improved plug-in configuration of the repetitive controller avoids the above problems while keeping all the advantageous features.

In some control tasks, such as those in robot manipulation, the systems to be controlled have constant or slowly-time varying uncertain parameters. Unless such parameter uncertainty is gradually reduced on-line by an appropriate adaptation or estimation mechanism, it may cause inaccuracy or instability for the control systems. In many other tasks, such as those in power systems, the system dynamics may have well known dynamics at the beginning, but experience unpredictable parameter variations as the control operation goes on. Without continuous redesign of the controller, the initially appropriate controller design may not be able to control the changing plant well.

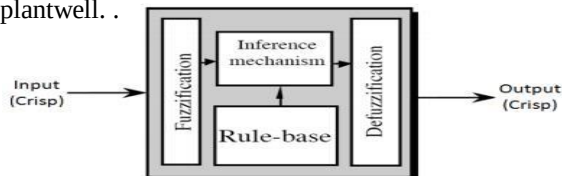


Fig 5: Fuzzy Logic Controller.

The problem of adaptation of dynamical systems having parameter uncertainty has attracted a lot of research efforts in all times. In particular, for nonlinear systems, several approaches have been proposed to deal with this important problem. On the other hand, as a model free design method, fuzzy logic systems have been successfully applied to control complex or mathematically poorly understandable systems. However, the fuzzy control has not been regarded as a rigorous science due to the lack of guaranteed global stability and acceptable performance.

To overcome these drawbacks, during the last decade, there has been growing interest in systematic analysis and design of fuzzy control systems such as stability and robustness. In recent years, in order to deal with the uncertainties of nonlinear systems in the fuzzy control system literature, a lot of effort has been put to adaptive fuzzy control system such as neural network based approaches, and the TS model based approaches.

Rulebase, inference mechanism and defuzzification methods are the sources of nonlinearities in FLCs. But it's possible to construct a rule base with linear input-output characteristics. For an FLC to become a linear controller with a control signal $U = E + CE$. Where

E is error and CE is change of error, some conditions must be satisfied :

1. Support sets of input linguistic variables must be large enough so that input values stay in limits.
2. Linguistic values must consist of symmetric triangular fuzzy sets that intercept with neighbouring sets at a membership value of so that for any time instant, membership values add to 1.
3. Rule base must consist of -combinations of all fuzzysets. Output linguistic variables must consist of singleton fuzzy sets positioned at the sum of the peak positions of input fuzzy sets.
4. Should be multiplication and defuzzification method must be centre of gravity (COGS).

V. Simulation Results

The large scale grid connected cascaded PV system with proposed control strategy is validated in cosimulation platform with MATLAB. The equivalent switching function model in phase a is shown in fig 6. The same model can be used in phase b and c. The single phase (a) results is shown in fig 7 and three phase results are shown in fig 8 and the fig 9 represents the total harmonic distortion in three phase voltage of the grid, the total harmonic distortion (THD) is reduced to 0.05% by using fuzzy logic.

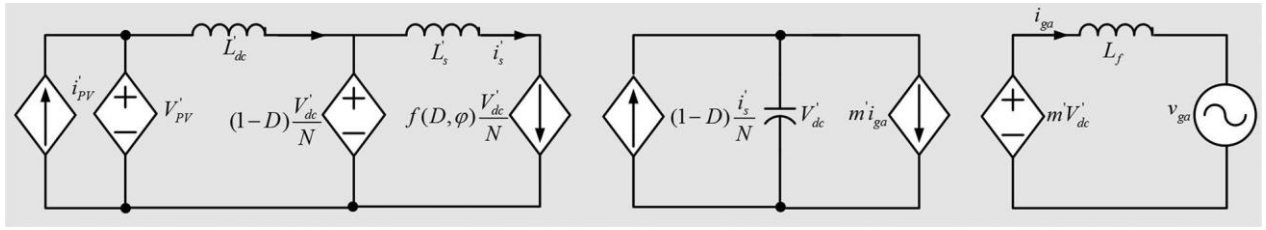


Fig. 6. Equivalent switching function model of the cascaded PV system in phase a .

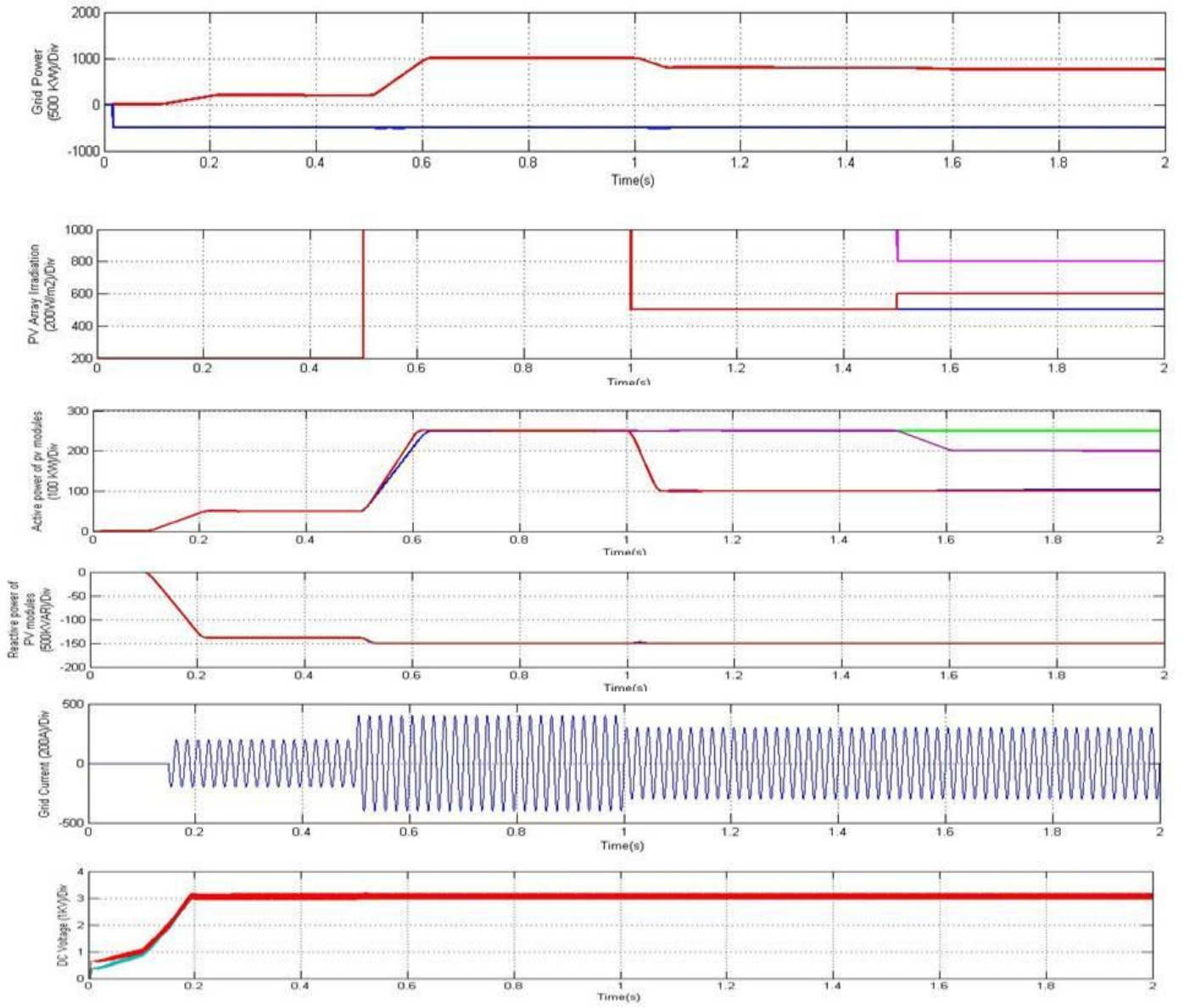


Fig. 7 Simulation results of PV system with the proposed control in phase a .

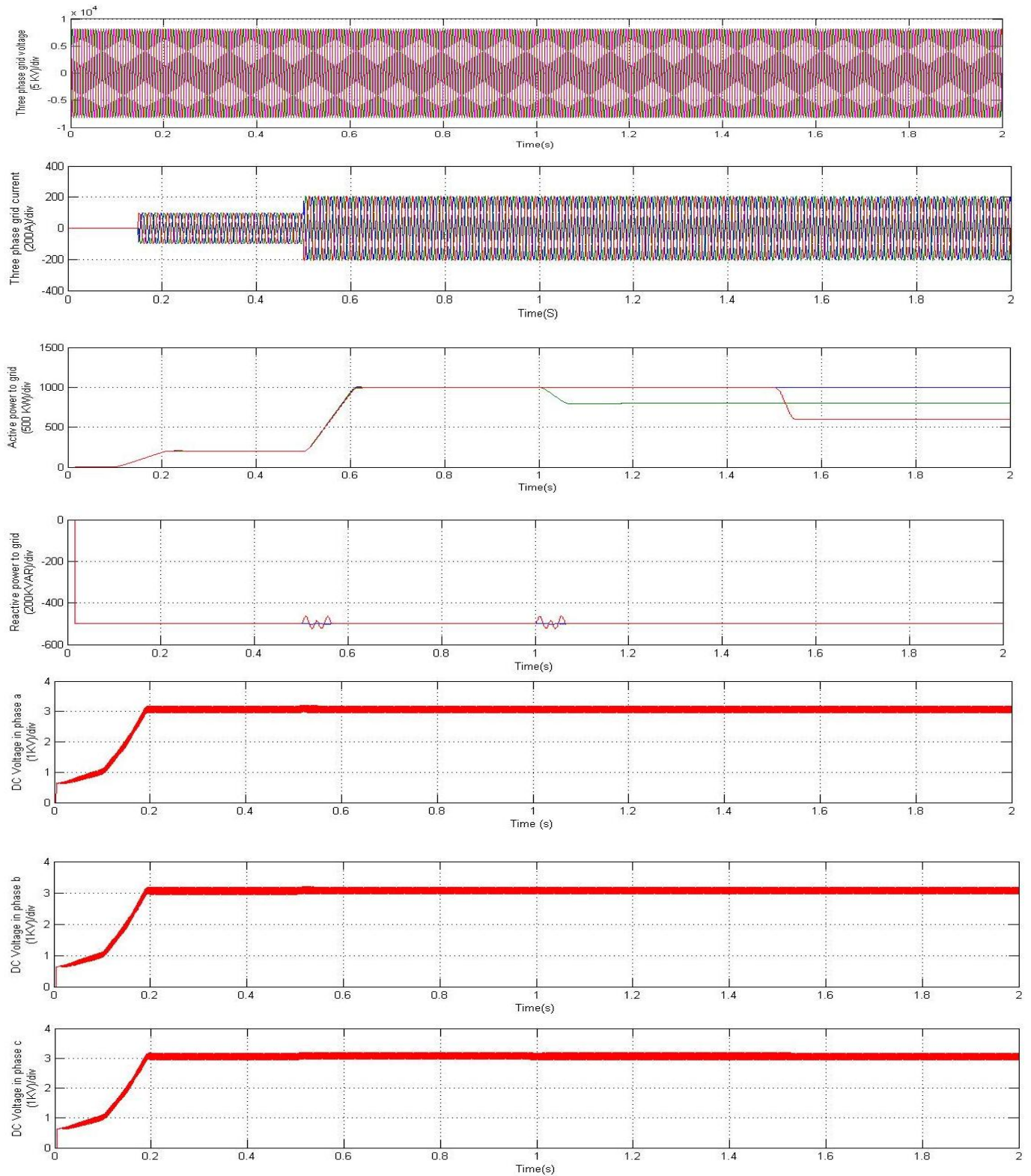


Fig. 8 Simulation results of PV system with the proposed control in three phase.

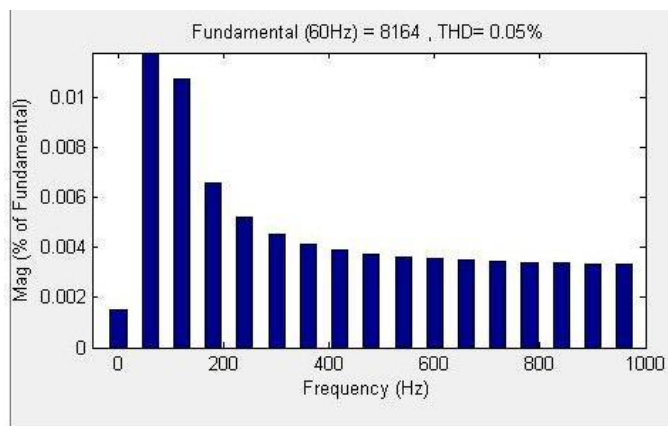


Fig 9 Harmonic spectrum of three phase voltage with the proposed control

VI. CONCLUSION

This paper addressed the active and reactive power distribution among cascaded PV inverter modules and their impacts on power quality and system stability for the large-scale grid-connected cascaded PV system. The output voltage for each module was separated based on grid current synchronization to achieve independent active and reactive power distribution. A decoupled active and reactive power control strategy was developed to enhance system operation performance. The proposed control strategy enabled the cascaded PV inverter modules to adequately embody their respective reactive power compensation capability regardless of their active power generation. Moreover, it was demonstrated that the risk of overmodulation of the output voltage from the cascaded PV inverter modules can be effectively reduced, which improves system power quality and stability. Correspondingly, the simulation and experimental results confirmed the validity of the proposed control strategy.

REFERENCES

- [1] Y. Bo, L. Wuhua, Z. Yi, and H. Xiangning, "Design and analysis of a grid connected photovoltaic power system," *IEEE Trans. Power Electron.*, vol. 25, no. 4, pp. 992–1000, Apr. 2010.
- [2] J. Ebrahimi, E. Babaei, and G. B. Gharehpetian, "A new topology of cascaded multilevel converters with reduced number of components for high-voltage applications," *IEEE Trans. Power Electron.*, vol. 26, no. 11, pp. 3109–3118, Nov. 2011.
- [3] L. Nousiainen and J. Puukko, "Photovoltaic generator as an input source for power electronic converters," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 3028–3037, Jun. 2013.
- [4] D. Meneses, F. Blaabjerg, O. Garcia, and J. A. Cobos, "Review and comparison of step-up transformerless topologies for photovoltaic AC-module application," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2649–2663, Jun. 2013.
- [5] S. Kjaer, J. Pedersen, and F. Blaabjerg, "A review of single-phase grid connected inverters for photovoltaic modules," *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.
- [6] J. Mei, B. Xiao, K. Shen, L. M. Tolbert, and J. Y. Zheng, "Modular multilevel inverter with new modulation method and its application to photo-voltaic grid-connected generator," *IEEE Trans. Power Electron.*, vol. 28, no. 11, pp. 5063–5073, Nov. 2013.
- [7] Y. Zhou, L. Liu, and H. Li, "A high performance photovoltaic module-integrated converter (MIC) based on cascaded quasi-Z-source Inverters (qZSI) using eGaN FETs," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2727–2738, Jun. 2013.
- [8] L. Liu, H. Li, and Y. Zhou, "A cascaded photovoltaic system integrating segmented energy storages with self-regulating power distribution control and wide range reactive power compensation," *IEEE Trans. Power Electron.*, vol. 26, no. 12, pp. 3545–3559, Dec. 2011.
- [9] Q. Li and P. Wolfs, "A review of the single phase photovoltaic module integrated converter topologies with three different DC link configurations," *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1320–1333, May 2008.
- [10] L. Zhang, K. Sun, Y. Xing, L. Feng, and H. Ge, "A modular grid-connected photovoltaic generation system based on DC bus," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 523–531, Feb. 2011.
- [11] L. M. Tolbert and F. Z. Peng, "Multilevel converters as a utility interface for renewable energy systems," in *Proc. IEEE Power Eng. Soc. Summer Meet.*, Seattle, Washington, USA, Jul. 2000, pp. 1271–1274.
- [12] M. Malinowski, K. Gopakumar, J. Rodriguez, and M. A. Perez, "A survey on cascaded multilevel inverters," *IEEE Trans. Ind. Electron.*, vol. 57, no. 7, pp. 2197–2206, Jul. 2010.
- [13] S. Harb and R. S. Balog, "Reliability of candidate photovoltaic module-integrated-inverter (PV-MII) topologies—A usage model approach," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 3019–3027, Jun. 2013.
- [14] L. Liu, H. Li, and Y. Xue, "A coordinated active and reactive power control strategy for grid-connected cascaded photovoltaic (PV) system in high voltage high power applications," in *Proc. IEEE 28th Appl. Power Elec-tron. Conf. Expo.*, Long Beach, CA, USA, Mar. 17–21, 2013, pp. 1301–1308.
- [15] P. Denholm and R. Margolis, "Very large-scale deployment of grid-connected solar photovoltaics in the united states: Challenges and opportunities," in *Proc. Nat. Renewable Energy Laboratory Conf. Paper Preprint Solar*, U.S. Department of Energy, 2006.
- [16] M. Abolhassani, "Modular multipulse rectifier transformers in symmetrical cascaded H-bridge medium voltage drive," *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 698–705, Feb. 2012.
- [17] K. Sano and M. Takasaki, "A transformerless D-STATCOM based on a multivoltage cascaded converter requiring no dc source," *IEEE Trans. Power Electron.*, vol. 27, no. 6, pp. 2783–2795, Jun. 2012.
- [18] C. D. Townsend, T. J. Summers, J. Volden, A. J. Watson, R. E. Betz, and J. C. Clare, "Optimization of switching losses and capacitor voltage ripple using model predictive control of a cascaded H-bridge multilevel StatCom," *IEEE Trans. Power Electron.*, vol. 28, no. 7, pp. 3077–3087, Jul. 2013.
- [19] B. Gultekin and M. Ermis, "Cascaded multi-level converter-based trans-mission STATCOM: System design methodology and development of a 12 kV $\pm$ 12 MVar power stage," *IEEE Trans. Power Electron.*, vol. 28, no. 11, pp. 4930–4950, Nov. 2013.
- [20] T. Zhao, G. Wang, S. Battacharya, and A. Q. Huang, "Voltage and power balance control for a cascaded H-bridge converter-based solid-state trans-former," *IEEE Trans. Power Electron.*, vol. 28, no. 4, pp. 1523–1532, Apr. 2013.
- [21] X. She, A. Q. Huang, and X. Ni, "Current sensorless power balance strategy for DC/DC converters in a cascaded multilevel converter based solid state transformer," *IEEE Trans. Power Electron.*, vol. 29, no. 1, pp. 17–22, Jan. 2014.
- [22] S. Du, J. Liu, and J. Lin, "Hybrid cascaded H-bridge converter for harmonic current compensation," *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2170–2179, May. 2013.
- [23] E. Villanueva, P. Correa, J. Rodriguez, and M. Pacas, "Control of a single-phase cascaded h-Bridge multilevel inverter for grid-connected photovoltaic systems," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4399–4406, Sep. 2009.
- [24] O. Alonso, P. Sanchis, E. Gubia, and L. Marroyo, "Cascaded H-bridge multilevel converter for grid connected photovoltaic generators with independent maximum power point tracking of each solar array," in *Proc. IEEE 34th Annu. Power Electron. Spec. Conf.*, Jun. 2003, vol. 2, pp. 731–735.
- [25] J. Negroni, F. Guinjoan, C. Meza, D. Biel, and P. Sanchis, "Energy sampled data modeling of a cascade H-bridge multilevel converter for grid-connected PV systems," in *Proc. IEEE 10th Int. Power Electron. Congr.*, Oct. 2006, pp. 1–6.
- [26] F. C. Cecati and P. Siano, "A multilevel inverter for photovoltaic systems with fuzzy logic control," *IEEE Trans. Ind. Electron.*, vol. 57, no. 12, pp. 4115–4125, Dec. 2010.
- [27] M. Rezaei, H. Iman-Eini, and S. Farhangi, "Grid-connected photovoltaic system based on a cascaded H-Bridge inverter," *J. Power Electron.*, vol. 12, no. 4, pp. 578–586, Jul. 2002.
- [28] Y. Zhou and H. Li, "Leakage current suppression for PV cascaded multilevel inverter using GaN devices," in *Proc. IEEE 5th Energy Convers.*
- [29] *Congr. Expo.*, Denver, Colorado, USA, Sep. 15–19, 2013, pp. 1304–1310.
- [30] L. Liu, H. Li, Y. Xue, and W. Liu, "Reactive power compensation and

optimization strategy for grid-interactive cascaded photovoltaic systems,” accepted by *IEEE Trans. Power Electron.*, 2014.

- [31] W. Zhao, H. Choi, G. Konstantinou, M. Ciobotaru, and V. G. Agelidis, “Cascaded H-bridge multilevel converter for large-scale PV grid-integration with isolated dc-dc stage,” in *Proc. 3rd Int. Symp. Power Electron. Distrib. Generation Syst.*, Aalborg, Denmark, Jun. 25–28, 2012, pp. 849–856.
- [32] H. Choi, W. Zhao, M. Ciobotaru, and V. G. Agelidis, “Large-scale PV system based on the multiphase isolated DC/DC converter,” in *Proc. 3rd Int. Symp. Power Electron. Distrib. Generation Syst.*, Aalborg, Denmark, Jun. 25–28, 2012, pp. 801–807.
- [33] Y. Shi, L. Liu, H. Li, and Y. Xue, “A single-phase grid-connected PV converter with minimal DC-link capacitor and low-frequency ripple-free maximum power point tracking,” in *Proc. IEEE 5th Energy Convers. Congr. Expo.*, Denver, Colorado, USA, Sep. 15–19, 2013, pp. 2385–2390.
- [34] M. J. Ryan, R. W. D. Doncker, and R. D. Lorenz, “Decoupled control of a four-leg inverter via a new 4_4 transformation matrix,” *IEEE Trans. Power Electron.*, vol. 16, no. 5, pp. 694–701, Sep. 2001.
- [34] P. C. Loh, M. J. Newman, D. N. Zmood, and D. G. Holmes, “A comparative analysis of multi-loop voltage regulation strategies for single and three-phase UPS systems,” *IEEE Trans. Power Electron.*, vol. 18, no. 5, pp. 1176–1185, Sep. 2003.
- [35] P. C. Loh and D. G. Holmes, “Analysis of multiloop control strategies for LC/CL/LCL-filtered voltage-source and current-source inverters,” *IEEE Trans. Ind. Appl.*, vol. 41, no. 2, pp. 644–654, Mar./Apr. 2005.
- [36] A. Lindberg, “PWM and control of two and three level high power voltage source converters,” Licentiate thesis, Royal Inst. of Technology, Stockholm, Sweden, 1995.
- [37] H. Jin, “Behavior-mode simulation of power electronic circuits,” *IEEE Trans. Power Electron.*, vol. 12, no. 3, pp. 443–452, May 1997.

BIBILOGRAPHY:



Miss. R.R.MANISRI completed her B.tech and pursuing M.tech from Eluru College of engineering & technology. Her best part is that she galvanizes into the subject. She got more rewards and prizes at school, college level compilations. She is very much enthusiastic of knowing novel things.



Mr.N.P.V.L.R.C.SEKHAR, currently working as ASSOCIATE PROFESSOR at Eluru College of engineering & technology. His research and his enthusing interests include high development at his college applications.