ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

Harmonic Compensation Design with Multi-level Inverter

R.Madhumitha[1], C.Aravind[2], S. Gokula Brindha[3]

Assistant Professor, Dept. of EEE, Velalar College of Engineering and Technology, Erode, Tamilnadu, India[1]

Assistant Professor, Dept. of EIE, Kongu Engineering College, Erode, Tamilnadu, India[2]

Assistant Professor, Dept. of EEE, Velalar College of Engineering and Technology, Erode, Tamilnadu, India[1]

ABSTRACT: Due to the increased use of non-linear loads, the harmonics present in the voltage has been increased which has become a greater concern for the utility side. To mitigate the harmonic distortions the active or passive filters are used. But due to the development of power electronic converters now-a-days there is improvement in connection of renewable energy sources to the distribution system and also improving power quality with the help of Distributed Generation has become a promising idea. In this paper, a novel control strategy is presented that utilizes the grid-connected Distributed Energy Resources (DERs) to achieve maximum benefits from them when implemented in 1-phase 2-wire distribution systems. It utilizes a multi-level inverter to connect the DERs to the grid which provides better performance when compared to the conventional inverters. The multilevel inverter is controlled to perform as a multi-function device by incorporating shunt active power filter functionality for harmonic rejection with power injection. The effect of presence of capacitor at different locations has been analysed and compared. The results are validated with the MATLAB/ Simulink.

KEYWORDS: Distributed Energy Resource, Harmonic Compensation, Multi-level Inverter, Power Injection, Renewable Energy Source

I.INTRODUCTION

Today the major problem faced by the electric utilities and end users of electric power is the increasing energy demand. Fossil fuel is the only resource that is used for meeting the seventy five percentage of the energy demand of the world. The major issues faced in using the fossil fuels include air pollution, global warming, and reduction in fossil fuel availability which in turn made to look renewable energy sources for the future power generation. Distributed Generation (DG) is the integration of Renewable Energy Resources (RESs) at the distribution side. This may cause threats like stability, voltage regulation and Power-Quality (PQ) issues. Therefore, strict technical and regulatory system has to be complied for the DG systems for safe, reliable and efficient operation of the network. Since there is a great improvement of power electronics and digital control strategy, the PQ can be enhanced by actively controlling the DG systems. But the power electronics based equipment involving non-linear loads generate harmonic current, which reduces the quality of power as stated in [1]. The harmonic currents may result in voltage harmonics. The compensation of load current harmonics is usually carried out with Active Power Filters (APFs) at distribution level. The active power filtering is combined with the inverter interfacing the renewable RES with the grid, which reduces the extra hardware cost. The conventional inverter can be replaced by the multi-level inverter to provide better harmonic rejection.

II.SYSTEM MODELING

A. Solar Panel Modelling

Solar energy is generally used in the form of solar irradiance to produce electricity. The PV cell works with the Photoelectric effect principle which states that the light energy is converted to electric energy. These cells are made of semiconductor materials like silicon. A typical silicon solar cell generates about 0.5~0.6 volts in normal operation. Many solar cells are connected in series to form a module and many solar modules are connected to make solar arrays to meet the voltage requirement of the system.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

As stated in [2], the rating of a solar module is given by the maximum output or maximum power it can deliver. The output of a solar module depends on the number of cells in the module, type of cell and the total surface area. The output of a module changes depending on the amount of solar irradiance, the angle of the module with respect to the sun, the temperature of the module and the voltage at which the load is drawing power from the module. The Fig. 1 shows the equivalent circuit of the solar cell.

The solar panels are connected in series and parallel and it is used to convert solar energy into electrical energy. The electrical energy produced from the solar cell depends on the internal parameters of the cell, solar irradiance and cell temperature.

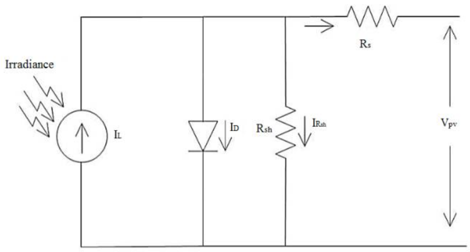

Fig. 1. Equivalent Circuit of Solar Cell

To increase PV Voltage solar cells are connected in series. In order to increase current they are connected in parallel. A solar panel of 48 V voltage rating has been used for the simulation purpose. 72 cells are connected together in series to form a module to produce 48 V. Each 48 V solar panel is connected to each stage of multi-level inverter. Table 1 shows the parameters for one cell in 48V module. Normally the solar irradiance value under Standard Test Condition (STC) is 1000 W/m^2, 25^o C.

TABLE 1 SOLAR CELL PARAMETERS

Parameters	Values
Short Circuit Current	7.34 A
Open Circuit Voltage	0.6 V
Ideality Factor	1.5
Series Resistance	0.037998 Ω

B. Multi-level Inverter Modelling

Plentiful multilevel converter topologies have been proposed during the last two decades. The modified laddered multi-level inverter topology as proposed in [3] with the least number of switches has been used in order to overcome the disadvantage. This topology uses one voltage source and two switches for each stage. For m-level inverter, (m-1)/2 stages are enough to produce m-levels of voltage. The number of batteries and switches required are reduced to half. If each stage is capable of producing voltage E, then n stages are capable of producing peak voltage of n*E. The output from these stages is a positive pulsed waveform. This output is converted to AC with the help of two pole two throw switch.

In this topology, the 48V solar panel is connected to each stage. A peak voltage of 336 V is generated with 7 stages. The 15 level output voltage is generated. These stage switches are controlled by the gate pulse generated

C. AC Source Modelling

An AC Source is modeled to be the voltage generated from the voltage side. The Voltage Source is modeled to produce a peak voltage of 336V with the frequency of 50Hz. The peak voltage of AC Source is assumed to be equal to the peak voltage generated with the help of multi-level inverter.

D. Transmission Line Modelling

Power generated from the generation side is fed through the transmission line to the load side. The transmission line has its own resistance, inductance and capacitance values. The resistance value in the transmission line is due to the opposition to the flow of current by the conductor. The inductance value of the transmission line is due to the magnetic

 DOI:10.15662/IJAREEIE.2016.0509059

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

field around the conductor produced by the current flowing through the conductor. The capacitance value is due to the charges between the lines. Here a short transmission line has been used. Hence it contains only resistance and inductance. Based on the works done in [4] the transmission lines have been modeled. The source side transmission line parameters are 0.1Ω and 3mH and the load side transmission line parameters are chosen as 0.1Ω and 1 mH. The line feeding from the Active Power Filter to the load has resistance and inductance value as 0.1Ω and 2mH.

E. Load Modelling

The non-linear load introduces the harmonics in current waveform which in turn introduces harmonics in voltage waveform also. Here, a diode bridge rectifier fed RLC load used for non-linear load. The Resistance, Inductance and Capacitance are chosen as 10Ω, 10mH and 100μF respectively.

III.GATE PULSE GENERATION

A control system presented in [5] is concise and requires less computational effort than many others found in the literature. It is formed by a DC voltage regulator and reference current calculation. Also Multiple PWM Generation is used for generating switching signals to force the desired current into the system. Control algorithm as a flow chart in Fig. 2.

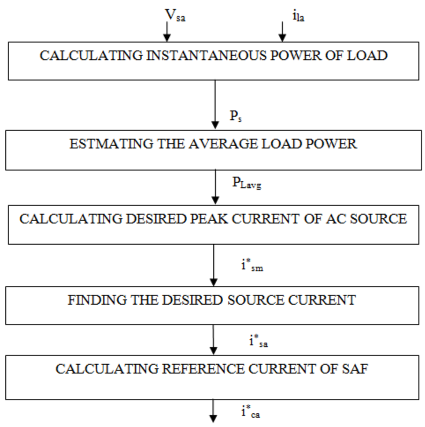

Fig. 2. Flow Chart for Reference Current Generation

The compensating current of active filter is calculated by sensing the load currents, DC bus voltage, and peak voltage of the AC source (V_{sm}). The instantaneous voltages of AC source can be represented in Eqn. (1).

$$V_{sa(t)} = V_{sm} \times \sin(\omega t) \tag{1}$$

The basic function of the proposed shunt active filter is to eliminate harmonics and also to provide a power injection. After compensating, the AC source feeds fundamental active power component of the load current and losses of inverter for regulating the DC link voltage. Therefore the peak of source reference current (i^*_{sm}) has two components.

The first component is corresponding to the average load active power (i^*_{smp}). The second component of AC source current (i^*_{smd}) is obtained from DC capacitor voltage regulator. Instantaneous power of load (at Kth sample) can be represented as given in the Equation. (2).

$$P_{load}(k)=V_{sa(k)}I_{la(k)} \tag{2}$$

The average power of load (P_{Lavg}) is obtained by passing P_{load} (k) to low pass filter. The average power of load (P_{Lavg}) is given in the Equation (3) and the number of samples is given in the Equation (4).

$$P_{Lavg} =1/n \sum P_{load(k)} \tag{3}$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

$$n=Tf_s;T=1/f \quad (4)$$

Here, f is the fundamental system frequency,f_s is the sampling frequency.

In order to compensate the current harmonics and reactive power of load, the average active power of AC source must be equal with P_{Lavg}. Considering the unity power factor for AC source side currents the average active power of AC source can be represented as the Equation (5).

$$P_s= V_{sm}i^*_{smp}= P_{Lav} \quad (5)$$

In the Equation (6) the first component of AC side current can be represented and named i^*_{smp}.

$$i^*_{smp}=P_{Lavg}/V_{sm} \quad (6)$$

The second component of AC source current (i^*_{smd}) is obtained from DC capacitor voltage regulator can be represented as in the Equation (7).

$$V^*_{cdc} = V_{dcref} - V_{cdc} \quad (7)$$

This (V^*_{cdc}) will be given to the PI controller and divided by the virtual resistance as stated in [6] to obtain i^*_{smd}. The K_p and T_i values are chosen as 0.345 and 34.9 based on the work done in [7]. The desired peak current of AC source can be given as the Equation (8).

$$i^*_{sm} =i^*_{smp}+i^*_{smd} \quad (8)$$

The AC source current must be sinusoidal and in phase with source voltages. Therefore the desired currents of AC source can be calculated by multiplying peak source current to a unity sinusoidal signal. The Equation (9) represents unity signals.

$$u_a=V_{sa}/V_{sm} \quad (9)$$

The desired source side current can be represented as given by the Equation (10) and it is denoted as i^*_{sa}.

$$i^*_{sa}=i^*_{sm}\times u_a \quad (10)$$

Finally, the reference currents of active filter can be obtained by subtracting the load current from the reference source current. This can be represented as the Equation (11).

$$i^*_{ca}=i^*_{sa}-i_{la} \quad (11)$$

This reference current will be given to the switching circuit, i.e., PWM controller for producing the necessary switching pulse to the voltage source inverter. So the voltage source inverter with the closed loop system acts as a controlled current source and produces the exact reference waveform at the output. This output of the shunt active filter compensates the line harmonics and the line current becomes sinusoidal and also injects the power generated.

The Multicarrier PWM technique is simulated as per the circuit shown in the Fig. 3. In the Fig. 3, the error signal as reference through the ‘In’ connection port and the gate signals generated apply to the stages of multilevel inverter through the ‘Out’ connection port. As stated in [8]-[11], inverter with 15-level, 7 carriers with same frequency f_c and the same peak to peak amplitude A_c are disposed. The reference or modulation waveform has peak to peak amplitude A_r and frequency f_r. The reference waveform is compared with carrier signals and if it is greater than a carrier signal, then switch/device correspond to that carrier is switched ON and if the reference is less than carrier signals then device correspond to carrier is switched OFF. The frequency of the reference signal for determining the inverter output frequency f_o and its peak amplitude Ar controls the modulated index M and then in turn the rms output voltage V_o. Here the modulation index is defined as the ratio of amplitude of reference signal to the amplitude of the carrier signal.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

The rms output voltage can be varied by varying the modulation index M. If δ is the width of each pulse, then the rms output voltage can be found from the Equation (12).

$$V_o = V_s \sqrt{\frac{p\delta}{\pi}} \qquad (12)$$

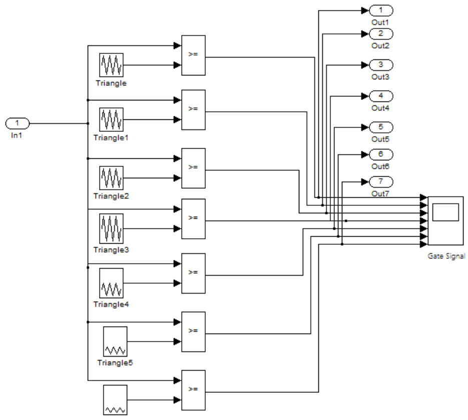

Fig. 3. Simulation of Gate Pulse Generation

IV. RESULTS AND DISCUSSION

The Simulation of the system with and without filter has been carried out for RLC load based on [12] with MATLAB Simulink. The results of the system without and with harmonic compensation are discussed below.

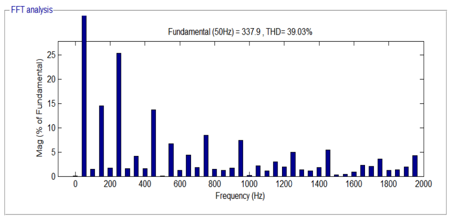

Fig. 4. Conventional Inverter Output Voltage Harmonics

From the Fig. 4 it is inferred that the Total Harmonic Distortion of the Output Voltage of the conventional inverter is 39.03%.

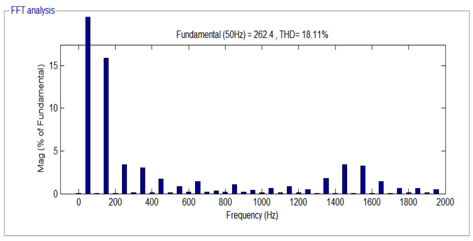

Fig. 5. Output Voltage Harmonics of Multi-level Inverter

From the Fig. 5, it is inferred that the 15-level inverter output voltage Total Harmonic Distortion (THD) is 18.11% for the same frequency and peak voltage of the conventional inverter output voltage.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

TABLE II TOTAL HARMONIC DISTORTION COMPARISON

Topology	Total Harmonic Distortion (%)
Conventional Inverter	39.03%
15-level Inverter	18.11%

From the Table II, it is observed that the multi-level Inverter provides better performance when compared to the Conventional Inverter and hence the work has been carried out with the 15-level Inverter.

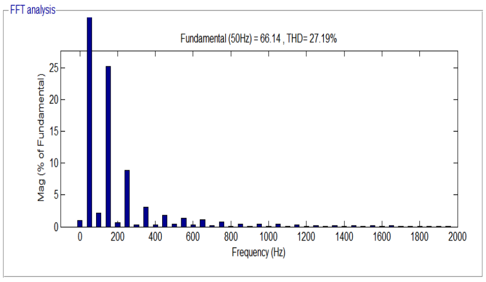

Fig. 6 Source Current Harmonics without filter

The Harmonics of the source current waveform is shown in the Fig. 6. From the Fig. 6, it is inferred that the Total Harmonic Distortion (THD) of the Source Current Waveform is 27.19%, which is above the IEEE norms and it has to be reduced by applying the control strategy.

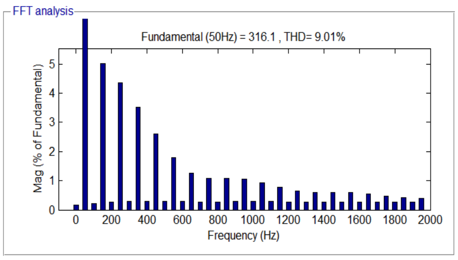

Fig. 7 Source Voltage Harmonics without Filter

The Fig. 7 shows the harmonics present in the source voltage caused due to the induction motor. From the Fig. 7, it is inferred that the Total Harmonic Distortion present in the voltage waveform i3 9.01%, which is above the IEEE norms i.e., 3%.

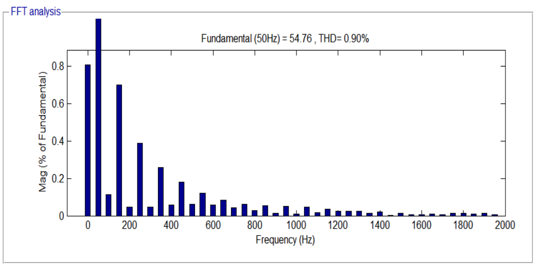

Fig. 8. Source Current Harmonics with Filter

From the Fig. 8, it is inferred that the Total Harmonic Distortion (THD) of the source current has been reduced to 0.90% which is within the limits of IEEE norms.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

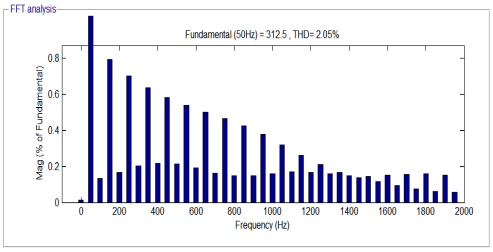

Fig. 9. Source Voltage Harmonics with Filter

The Fig.. 9 shows the source voltage harmonics after connecting the filter to the grid. The total Harmonic Distortion (THD) of the source voltage has been reduced to 2.05%, which is in limits of the IEEE standard.

TABLE III VOLTAGE AND CURRENT HARMONICS

Harmonics	Without Filter	With Filter
Current Harmonics	27.19%	0.90%
Voltage Harmonics	9.01%	2.05%

From the Table III, it is inferred that after connecting the filter to the grid, the THD has come into the permissible limits specified by the IEEE standards.

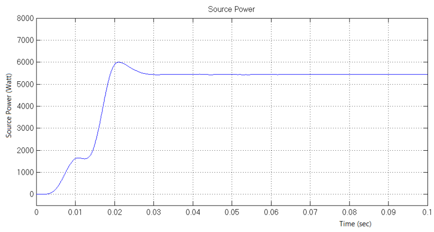

Fig. 10. Grid Power without Filter

The Fig. 10 shows the active power in the grid when the filter is not connected to the grid. The active power of the grid is 5200W.

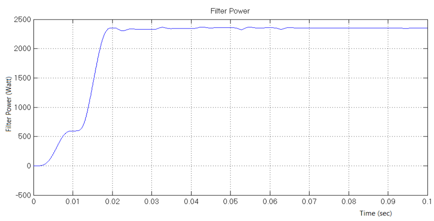

Fig. 11. Filter Output Power

The Fig. 11 shows the active power output from the filter. The active power from the filter is 2400W.

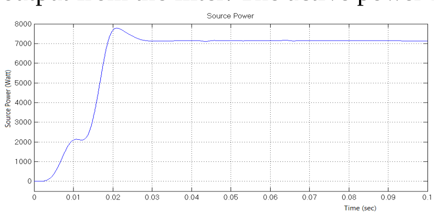

Fig. 12. Grid Power with Filter

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

The Fig. 12 shows the active power in the grid when connected to the filter. From the Fig. 12, it can be inferred that the output power has raised from 5200W to 7200W. This raise in power has proved that the power has been injected from the filter.

V. CONCLUSION

The grid interfacing inverter has been effectively utilized for power conditioning along with its normal operation of real power transfer. The grid interfacing inverter can be utilized to inject real power generated from RES to the grid and operate as a shunt Active Power Filter (APF). This method eliminates the need for additional power conditioning equipment to improve quality of power. Extensive MATLAB/ Simulink has been used to validate the proposed method and then it shows that the grid - interfacing inverter can be utilized as a multi-function device. The current harmonics are compensated effectively so that current waveform is always nearly sinusoidal. On controlling the proposed multilevel inverter topology, the Total Harmonic Distortion has been reduced from 27.19% to 0.90% which is in the allowable limit of IEEE. The work can be further preceded with Fuzzy Controller to provide better results. This work can also be extended to three phase system with the multi-level inverter topology.

REFERENCES

[1] Enslin. J. H. R, Heskes P. J. M, “Harmonic Interaction between a Large Number of Distributed Power Inverters and the Distribution Network”, IEEE Transactions on Power Electronics, vol.19, no.6, pp. 1586-1593, 2004.
[2] Paras Karki, Brijesh Adhikary, “MATLAB / Simulink based Modeling and Simulation of Grid-connected Solar Photovoltaic System in Distribution Power Network’, Fifth International Conference on Power and Energy Systems, 2013.
[3] Fang Lin Luo, Hong Ye, “Laddered Multilevel DC / AC Inverters Used in Solar Panel Energy Systems”, IET Journal on Power Electronics, vol.6 no.9, pp. 1769-1777, 2013.
[4] Yonbin Chu, Shuo Wang, Russell Crosier, “Grid Active Power Filters using Cascaded Multilevel Inverters with Direct Asymmetric Switching Angle Control for Grid Support Functions”, Applied Power Electronics Conference and Exposition, pp. 1332-1338, 2013.
[5] Mukthiar Singh, Vinod Khadkikar, Ambrish Chandra, Rajiv K. Varma, “Grid Interconnection of Renewable Energy Sources at the Distribution Level with Power-Quality Improvement Features”, IEEE Transactions on Power Delivery, vol.26 no.1 pp.307-315, 2011.
[6] Md Shirajum Munir, Yun Wei Li (2013), ‘Residential Distribution System Harmonic Compensation using PV Interfacing Inverter’, IEEE Transactions on Smart Grid, Vol.4 No.2 pp.816-827.
[7] Anooja. C. L, Leena. N, “Single Phase Shunt Active Filter with Fuzzy Controller for Harmonic Mitigation”, International Journal of Scientific and Engineering Research, vol.4 no.9 pp. 445-451, 2013.
[8] Vinod Kumar. P, Santhosh Kumar. Ch, Ramesh Reddy. K, “Single Phase Cascaded Multilevel Inverter using Multicarrier PWM Technique”, ARPN Journal of Engineering and Applied Sciences, vol.8 no.10 pp.796-799, 2013.
[9] Yonbin Chu, Shuo Wang, Russell Crosier , “Grid Active Power Filters using Cascaded Multilevel Inverters with Direct Asymmetric Switching Angle Control for Grid Support Functions”, Applied Power Electronics Conference and Exposition, pp. 1332-1338, 2013.
[10] Rodriguez. J, Lai. J. S, Peng. F. Z, “Multilevel Inverters: Survey of Topologies, Controls and Applications”, IEEE Transactions on Industry Applications, vol.49 no.4 pp.724-738, 2002.
[11] Rajasekar. S, Senthilkumar. A, Shasi Kumar. Y, Ajay-D-Vimalraj. P, “Power Quality Enhancement using Cascaded Multilevel Inverter based Shunt Hybrid Active Power Filter”, International Journal of Engineering, Science and Technology, vol. 3, no. 9, pp.37 - 46, 2011.
[12] Madhumitha, R., R. Vinothkumar. "Voltage regulation in mircogrid using adaptive controller." International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE), 2014.