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ANSYS-Maxwell based design of high frequency link for grid connection of renewable energy sources using MLI

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Currently, high frequency transformer for power MLIs is used for renewable energy interfacing applications. With the advancement in magnetic materials properties have led to the development of high frequency transformers for converters. Recently high frequency based magnetic material offers high saturation flux density and low core losses, used for designing of compact, light weight and efficient transformers. However, the designing of magnetic material is based on electro-magnetic concepts. So here, electro magnetic based software "ANSYS-Maxwell^{TM}" is used to design a high frequency transformer in 2-D geometry. The design methodology is illustrated to optimize it with minimum core losses, copper losses in the high frequency transformer.

Keywords: *Multi Level Inverter (MLI), high frequency magnetic link, ANSYS-Maxwell^{TM} software.*

1.0 INTRODUCTION

Development of renewable energy sources are increasing due to the growing concern of global warming and limited availability of conventional energy sources. [1-3,8]. PV energy is the most popular energy source available in the industries nowadays and fuel cell energy source is well suited in different distributed generation applications due to its flexibility in connection, easily stacked to serve larger loads, provide reliability and low emissions [4-6] . But the major disadvantage of these two sources is PV is intermittent in nature and dynamic performance of fuel cell is poor when the load changes suddenly. In order to overcome this problem, use of hybrid energy sources not only increases the power capability of the system but also increases reliability of the system. PV source along with fuel cell can be a stable system, used in grid integration applications [9]. Power converters act as a power processing unit for renewable energy sources. Conventional two level inverter produces low output voltage and used fundamental frequency transformer and filter at load side to maintain grid voltage level [10]. Requirement of step-up transformer and filter increases the weight, volume and cost of the system. Hence, transforemerless and filterless, multilevel inverter based system can be a viable option to alleviate this problem [11]. High number of level attainability in multilevel inverter implies elimination of transformer and filter at load side. Moreover, this approach does not provide isolation in the system therefore High Frequency Magnetic Link (HFML) is used to eliminate this problem. Compared with fundamental frequency transformers, high frequency transformers not only provides smaller size, cost but also offers isolation and reduce voltage imabalance problem. Rabiul *et al.*, presented the design of high frequency transformer in [7]. The objective of this paper is to develop a new system configuration for interfacing the PV along with fuel cell to the grid. Proposed configuration uses multilevel converter along with HFML for DC/AC conversion at a desired frequency. Designing of high frequency

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transformer is done on ANSYS-PExprt™, analysis in ANSYS-Maxwell™ and complete system simulation in ANSYS-Simplorer™ software.

2.0 PROPOSED SYSTEM

Block diagram of the proposed system is shown in the Figure 1. In the proposed system the DC to AC conversion take place using HFML with multilevel inverter.

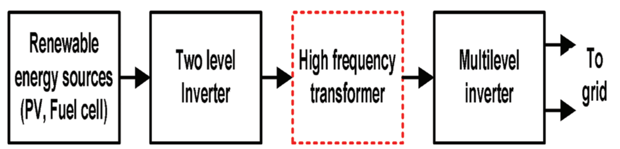

FIG. 1 BLOCK DIAGRAM OF THE PROPOSED SYSTEM

Elaborate image of the proposed system is shown in Figure 2.

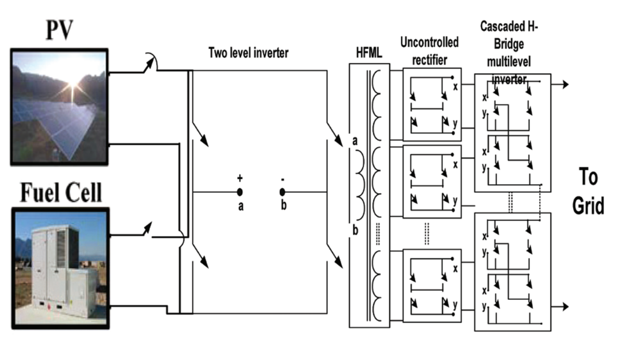

FIG. 2 ELLABORATE PROPOSED SYSTEM

Energy of PV is converted into high frequency AC signal using two level inverter and converterd into number of step up AC signals using HFML and given to the DC (uncontrolled rectifier)-AC (cascaded H-Bridge multilevel inverter) unit, feeding to the grid. Cascaded H-Bridge multilevel inverter is classical multilevel inverter, highly used in industries for high voltage and power applications. It is popular due to its modularity in structure compared to other classical inverters neutral point clamped (NPC) and flying capacitor (FC) multilevel inverter. In the proposed sytem, PV energy source is used as a primary source and fuel cell as a back-up source to maintain the reliability of the system.

3.0 HIGH FREQUENCY MAGNETIC LINK (HFML) DESIGN

In the designing of HFML, the important part is magnetic material of core and its availability in the market. Selection of core can be decided by the factor frequency. Increasing the frequency of the magnetic part reduces its size. For winding part generally litz wires are used because it is highly used in high voltage applications, having lower winding losses.

For high frequency application, number of magnetic materials are available in the market having high flux density, permeability and lower core losses. The list of magnetic materials is illustrated in Table 1 along with their flux density and frequency range. To design a transformer necessary general parameters are calculated as follows [12]:

$$P_t = P_{in} + \sum_{n=1}^{\infty} P_{o,n} \text{, watt} \quad ....(1)$$

$$P_{in} = \frac{P_o}{\eta} \text{, watt} \quad ....(2)$$

$$P_t = P_o\left(\frac{1}{\eta} + 1\right) \text{, watt} \quad ....(3)$$

$$K_e = 0.145 K_f^2 B_m^2 f^2 10^{-4} \quad ....(4)$$

$$K_g = \frac{P_t}{2K_e \alpha} \text{, cm}^5 \quad ....(5)$$

$$N_P = \frac{V_{in} 10^{-4}}{K_f B_{ac} f A_c} \text{, turns} \quad ....(6)$$

$$N_S = \frac{N_P V_S}{V_{in}}\left(1 + \frac{\alpha}{100}\right) \text{, turns} \quad ....(7)$$

Where,

Pt = Apparent power

P_{in} = Input power

P_o = Total output power

$P_{o,n}$ = Output power of n^{th} secondary winding

K_e = constant,

K_g = electrical design parameter

B_m = Maximum flux density

η = Efficiency

α = voltage regulation percentage

B_{ac} = Flux density

K_f = waveform coefficient

N_p = primary turns

N_s = Secondary turns

V_{in} = Input voltage

n = number of secondary windings

TABLE 1

TYPICAL MAGNETIC MATERIAL PROPERTIES

MATERIALS	MODEL	B_{PEAK}	FREQUENCY
Ferrites	Epcos N87	0.49	upto 1 MHz
Nanocrystalline	Vitroperm 500F	1.2-1.5	upto 150 KHz
Amorphous	Metglas 2605	1.56	upto 250 KHz
Si iron	Unisil 23M3	2.0	upto 50 Hz
Ni-Fe (Permalloy)	Magnetics Permalloy 80	0.82	upto 20 KHz
Powdered iron	Micrometals 75 μ	0.6-1.5	upto 200 MHz

ANSYS™ provides number of software platforms for the development of products. Type of ANSYS software platform and its applications are listed in Figure 3.

ANSYS-PExprt™ software provides the platform to design, modelling, analysis and optimization of multiwinding transformer, coupled inductors and flyback components. It offers easy path to determine the core size and shape, air gaps and winding design parameters for a given converter. It is able to build 2D/3D maxwell designs to analyze the magnetic properties of the model such as flux density, current distribution in the windings etc. It also creates the magnetic model for the actual circuit in ANSYS simplorer for whole circuit analysis.

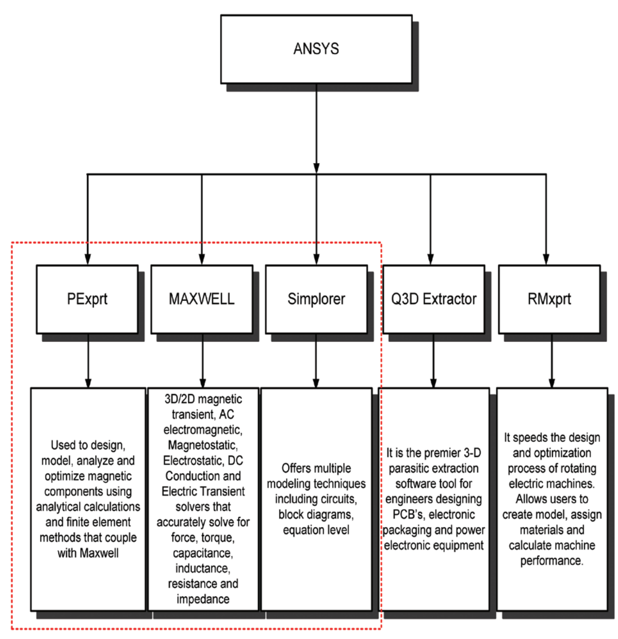

FIG. 3 ANSYS SOFTWARE PACKAGES

The simple flow chart to design a transformer in ANSYS-PExprt™ window is given in the Figure 4. To start the design process in the ANSYS-PExprt™ window, design input parameters- input voltage, number of primary and secondary turns (number of secondary windings depends on the numer of input sources of multilevel inverters), frequency, power wave shape type (either square and sinusoidal) and optimization criterion (for example-low losses, smallest size etc.) are given. Number of turns calculation and each secondary winding power can be obtained by using equations 1-7. After giving the required design parameters start simulation, if the model is optimized then stop the process otherwise change the design parameters or dimensions till design optimization. In PExprt window core and copper losses can also be found. After generating the model, it can be exported either in ANSYS-Maxwell window for analysis and in ANSYS-Simplorer window for simulating and analysing the whole circuit virtual prototype.

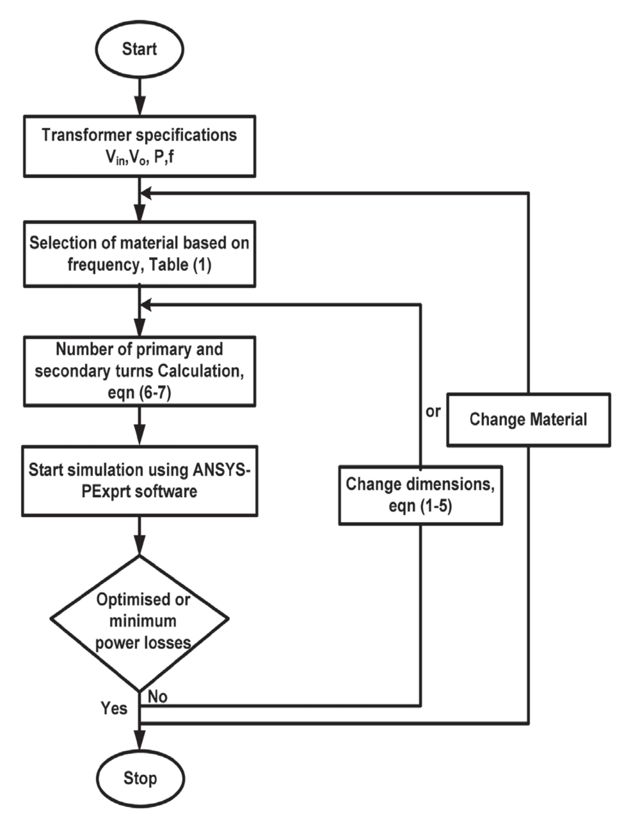

FIG. 4 FLOW CHART OF THE HIGH FREQUENCY TRANSFORMER DESIGNING

4.0 SIMULATION

Magnetic link shown in Figure 2 is designed and simulated in ANSYS-PExprt software window. The design window is depicted in Figures. 5-7 and Table 2 summarizes the simulated system specifications.

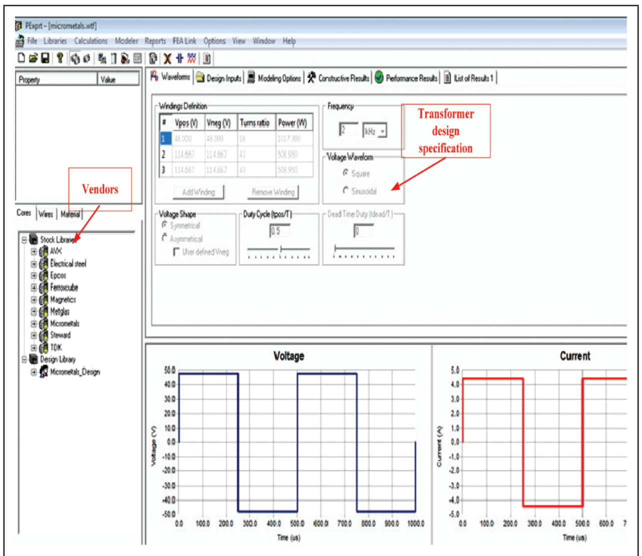

FIG. 5 ANSYS-PEXPRT INPUT PARAMETERS WINDOW

TABLE 2	
SYSTEM SPECIFICATIONS OF THE 1-Φ 5-LEVEL SYSTEM FOR THE SIMULATION	
PV / fuel cell voltage	48V
Frequency	2kHz
V_{in}	48V
V_o	115V
N_P	23
Ns	54
B_m	1
Power	1KW
α	0.5
η	95%
R	100Ω
Number of Secondary windings	2

Figure 5. is the ANSYS-PExprt window where input parameters are given for the designing of product. After simulation, product analysis can be done through its performance and construction window shown in Figures. 6-7. Performance window provides losses (core and copper) data, temperature of a designed model etc and modelling window offers core/winding properties and its dimensions for practical designing model.

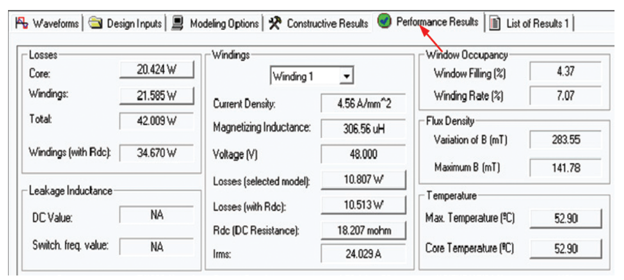

FIG. 6 ANSYS-PEXPRT CONSTRUCTIVE RESULT WINDOW

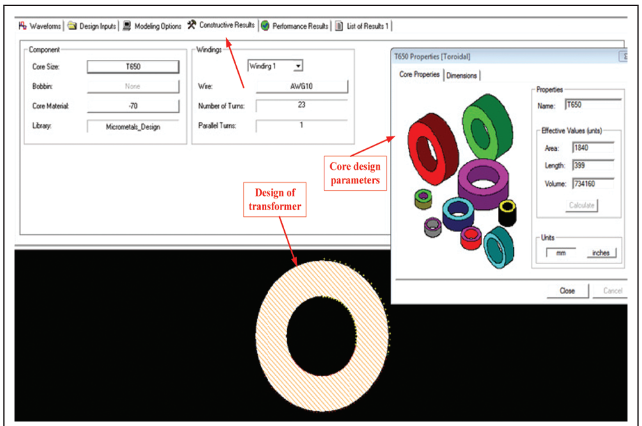

FIG. 7 ANSYS-PEXPRT MODELING WINDOW

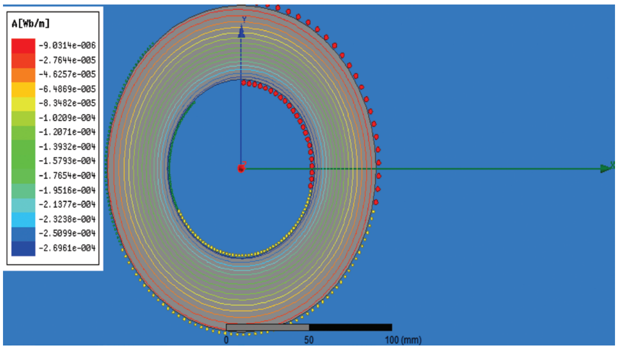

FIG. 8 FLUX DENSITY IN A TRANSFORMER CORE USING ANSYS-MAXWELL

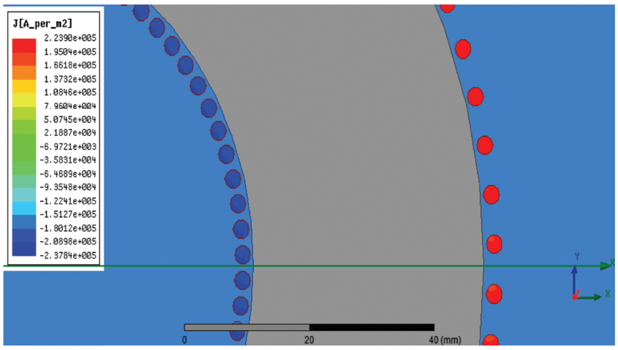

FIG. 9 CURRENT DENSITY IN A TRANSFORMER WINDING USING ANSYS-MAXWELL

Generated model in a ANSYS-PExprt™ can be analysed in ANSYS-Maxwell™ by exporting the model from ANSYS-PExprt™ to ANSYS-Maxwell™. Analysis of flux and current density in a model can be visualize in Figures 8-9. In Figures 8 and 9 colour band of flux and current density are clearly visible, to observe at which part of designed product these quantities are maximum and minimum.

ANSYS-Simplorer™ provides the platform for the system modelling, simulation and analysis of the whole system. Magnetic part is exported from the ANSYS-PExprt window to the ANSYS-Simplorer to develop the proposed system shown in Figure 2. Converter parts are designed in ANSYS-Simplorer. To design a 5-level multilevel inverter, symmetric cascaded H-Bridge requires two input DC sources (also decides number of secondary winding of transformer). Simulation model of the proposed system is presented in Figure 10.

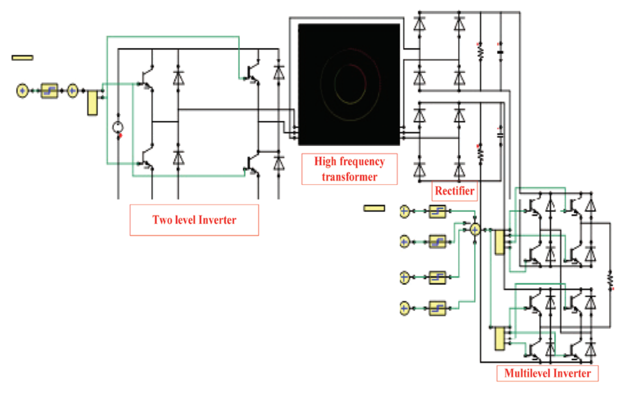

FIG. 10 SIMULATION MODEL OF THE PROPOSED SYSTEM IN ANSYS-SIMPLORER

Simulation results of transformer one of the secondary windings is shown in Figure 11. It generates voltage near about 100 V.

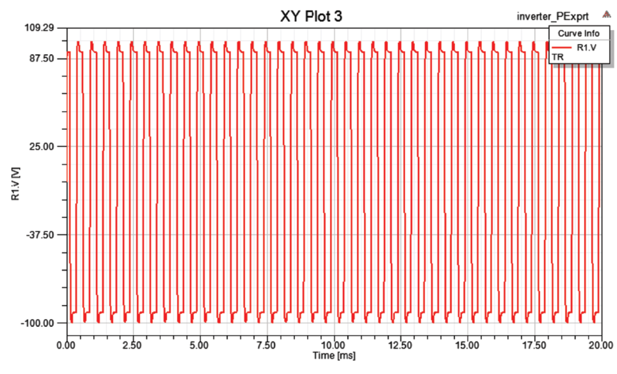

FIG.11 TRANSFORMER SECONDARY WINDING OUTPUT VOLTAGE

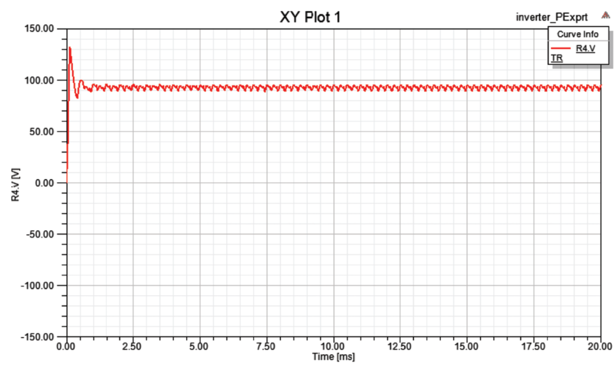

FIG. 12 RECTIFIED OUTPUT VOLTAGE OF UNCONTROLLED RECTIFIER

Rectified output voltage of uncontrolled rectifier is shown in Figure 12 and multilevel inverter 5-level output waveform is shown in Figure 13.

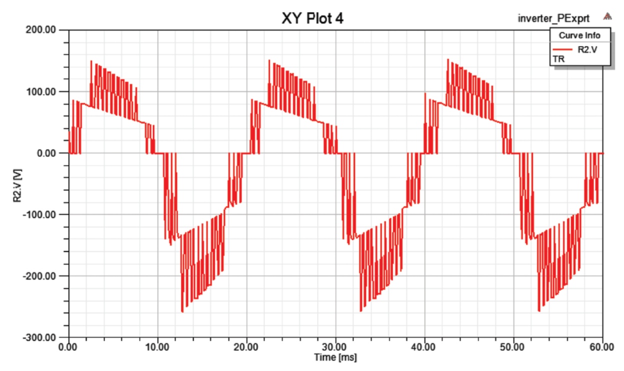

FIG. 13 OUTPUT VOLTAGE OF MULTILEVEL INVERTER

5.0 CONCLUSION

In this paper, a system is proposed for grid integration application. The designing of high frequency magnetic link is developed in ANSYS-PExprt™ software. ANSYS-PExprt™ software offers a simplest way for optimized designing of transformer along with designing data, useful for practical system implementation . ANSYS software not only provides the designing but also offers platforms for analysis (2D/3D visualization of flux and current density in the model) using ANSYS-Maxwell™ and simulation of the complete system in ANSYS-Simplorer™ software.

REFERENCES

[1] J M Carrasco, L G Franquelo, J T Bialasiewicz, E Galvan, R C P Guisado, Prats Ma A M, J I Leon, Moreno-Alfonso N Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey, in Industrial Electronics, IEEE Transactions on, Vol. 53, No. 4, pp.1002-1016, June 2006.

[2] S Dasgupta, S N Mohan, S K Sahoo, S Panda K, Application of Four-Switch-Based Three-Phase Grid-Connected Inverter to Connect Renewable Energy Source to a Generalized Unbalanced Microgrid System, in Industrial Electronics, IEEE Transactions on, Vol. 60, No. 3, pp.1204-1215, March 2013.

[3] S Alepuz, S Busquets-Monge, J Bordonau, Gago J, Gonzalez D, Balcells J., Interfacing Renewable Energy Sources to the Utility Grid Using a Three-Level Inverter, in Industrial Electronics, IEEE Transactions on, Vol. 53, No. 5, pp. 1504-1511, Oct. 2006.

[4] C Raga, A Barrado, A Lazaro, C Fernandez, V Valdivia, I Quesada, L Gauchia, Black-Box Model Identification Technique and Frequency Analysis for PEM Fuel Cell With Overshooted Transient Response, in Power Electronics, IEEE Transactions on, Vol. 29, No.10, pp. 5334-5346, Oct. 2014.

[5] A Debenjak, J Petrovcic, P Boskoski, B Musizza, D Juricic, Fuel Cell Condition Monitoring System Based on Interconnected DC–DC Converter and Voltage Monitor, in Industrial Electronics, IEEE Transactions on, Vol. 62, No. 8, pp. 5293-5305, Aug. 2015.

[6] F Gao, B Blunier, D Chrenko, D Bouquain, A Miraoui, Multirate Fuel Cell Emulation With Spatial Reduced Real-Time Fuel Cell Modeling in Industry Applications IEEE Transactions on, Vol. 48, No. 4, pp.1127-1135, July-Aug. 2012.

[7] M R Islam, G Youguang, A Jianguo Zhu, High-Frequency Link Multilevel Cascaded Medium-Voltage Converter for Direct Grid Integration of Renewable Energy Systems, in Power Electronics, IEEE Transactions on, Vol. 29, No. 8, pp. 4167-4182, Aug. 2014.

[8] B Frede B, Ke Ma, and Yongheng Yang, Power electronics for renewable energy systems. status and trends. In Integrated Power Systems (CIPS), 2014 8th International Conference on, pages 1–11, Feb 2014.

[9] H Rslan, M Ahmed, M Orabi, M Youssef Development of grid connected power conditioner system compatible with fuel

cell applications, in Power Electronics for Distributed Generation Systems (PEDG), 2010 2nd IEEE International Symposium on, Vol. No. pp. 935-941, 16-18 June 2010.

[10] Y Zhao, Y Zhang, D Wang, J Zhan, The circuit topology for single-phase grid-connected system and the control technology on converters, in Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on , Vol., No., pp.1-5, 6-7 April 2009.

[11] M R Islam, Youguang Guo; Jianguo Zhu, A transformer-less compact and light wind turbine generating system for offshore wind farms, in Power and Energy (PECon), 2012 IEEE International Conference on, Vol., No., pp.605-610, 2-5 Dec. 2012.

[12] W Colonel, T Mclyman, Transformer And Inductor Design Handbook, marcell dekker, inc. newyork. Barel, 2004.