

Real-Time Implementation of ANFIS Control for Renewable Interfacing Inverter with Capacitors in 3p4w Distribution Network

Tanneru Nagendhra Jyothi

Dept of Power Electronic and Drives,
Vasireddy Venkatadri Institute of Technology.

I.Subha Rani

Assistant Professor,
Dept of Power Electronic and Drives,
Vasireddy Venkatadri Institute of Technology.

Abstract:

Power electronics plays an important role in controlling the grid-connected renewable energy sources. This paper presents a novel adaptive neuro-fuzzy control approach for the renewable interfacing inverter. The main objective is to achieve smooth bidirectional power flow and nonlinear unbalanced load compensation simultaneously, where the conventional proportional-integral controller may fail due to the rapid change in the dynamics of the highly nonlinear system. The combined capability of neuro-fuzzy controller in handling the uncertainties and learning from the processes is proved to be advantageous while controlling the inverter under fluctuating operating conditions.

MATLAB:

2.1 Introduction to Matlab:

Matlab is a high-performance language for technical computing. The name mat lab stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building. Matlab is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

2.2 History of Matlab:

Cleve Barry Moler, the chairman of the computer-science department at the University of New Mexico, he is a mathematician and computer programmer

specializing in numerical analysis. Started developing MATLAB in the late 1970s. He designed it to give his students access to LINPACK and EISPACK without their having to learn Fortran. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983.

Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded Math Works in 1984 to continue its development. These rewritten libraries were known as JACK-PAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK.

2.3 Strengths of Matlab:

- MATLAB is relatively easy to learn.
- MATLAB code is optimized to be relatively quick when performing matrix operations.
- MATLAB may behave like a calculator or as a programming language.
- MATLAB is interpreted, errors are easier to fix.
- Although primarily procedural, MATLAB does have some object-oriented elements.

2.4 Other features:

- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, FORTRAN, Java, COM, and Microsoft Excel.

2.5 Components of Matlab:

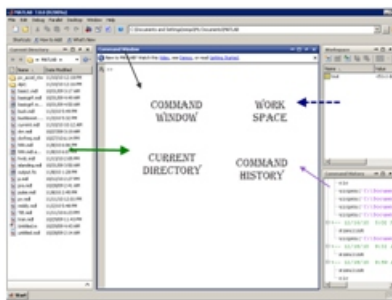
- Workspace
- Current Directory
- Command History

Command Window

Block diagram of Mat lab components.

2.6 MATLAB and engineering:

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing. However, many researchers mostly from Computer Science background feel that MATLAB should be used only for mathematical analysis necessary in image processing and not for implementation of image processing software. Moreover, MATLAB should not be used to simulate computer architectures, systems software and computer networks unless while solving some numeric problem.



2.7 Toolboxes in Matlab:

- Simulink
- Fuzzy
- Genetic algorithm
- Neural network
- Wavelet

2.8 Simulink:

» Introduction:

Simulink is a software add-on to mat lab which is a mathematical tool developed by The Math works, (<http://www.mathworks.com>) a company based in Natick. Mat lab is powered by extensive numerical analysis capability. Simulink is a tool used to visually program a dynamic system (those governed by Differential equations) and look at results. Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries.

Various toolboxes for different techniques, such as Fuzzy Logic, Neural Networks, DSP, Statistics etc. are available with Simulink, which enhance the processing power of the tool. The main advantage is the availability of templates / building blocks, which avoid the necessity of typing code for small mathematical processes.

» Concept of signal and logic flow:

In Simulink, data/information from various blocks are sent to another block by lines connecting the relevant blocks. Signals can be generated and fed into blocks dynamic / static). Data can be fed into functions. Data can then be dumped into sinks, which could be scopes, displays or could be saved to a file. Data can be connected from one block to another, can be branched, multiplexed etc. In simulation, data is processed and transferred only at discrete times, since all computers are discrete systems. Thus, a simulation time step (otherwise called an integration time step) is essential, and the selection of that step is determined by the fastest dynamics in the simulated system.

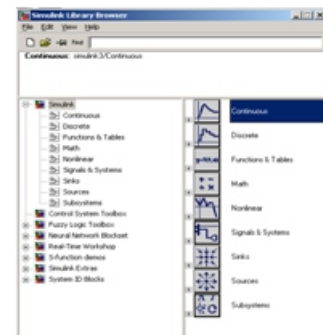


Fig 4.1 Simulink library browser

» Connecting blocks:

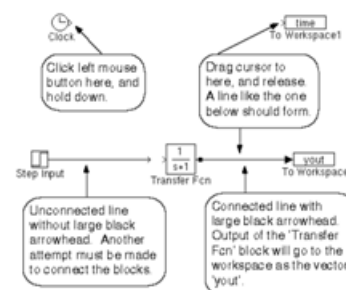


fig 4.2 Connecting blocks

To connect blocks, left-click and drag the mouse from the output of one block to the input of another block.

Sources and sinks:

The sources library contains the sources of data/signals that one would use in a dynamic system simulation. One may want to use a constant input, a sinusoidal wave, a step, a repeating sequence such as a pulse train, a ramp etc. One may want to test disturbance effects, and can use the random signal generator to simulate noise. The clock may be used to create a time index for plotting purposes. The ground could be used to connect to any unused port, to avoid warning messages indicating unconnected ports. The sinks are blocks where signals are terminated or ultimately used. In most cases, we would want to store the resulting data in a file, or a matrix of variables.

CONCEPT OF RENEWABLE ENERGY RESOURCE:

Introduction :

A natural resource qualifies as a renewable resource if its stock (quantity) can increase over time. Natural resources which qualify as renewable resources are, for example, oxygen, fresh water, solar energy, timber, and biomass. But they can become non-renewable resources if more of them is used than nature can reproduce in the same time at that place. For example ground water may be removed from an aquifer at a greater rate than that of new water flowing to that aquifer. Removal of water from the pore spaces may cause permanent compaction (subsidence) that cannot be reversed. Human consumption and use at sustainable levels primarily uses renewable resources versus non-renewable resources.

4.1 Difference between renewable and non-renewable resources:

Renewable energy:

Renewable energy is energy which is generated from natural sources i.e. sun, wind, rain, tides and can be generated again and again as and when required. They are available in plenty and by far most the cleanest sources of energy available on this planet. For e.g: Energy that we receive from the sun can be used to generate electricity. Similarly,

Pros:

- The sun, wind, geothermal, ocean energy are available in the abundant quantity and free to use.

- The non-renewable sources of energy that we are using are limited and are bound to expire one day.
- Renewable sources have low carbon emissions, therefore they are considered as green and environment friendly.

Cons:

- It is not easy to set up a plant as the initial costs are quite steep.
- Solar energy can be used during the day time and not during night or rainy season.
- Geothermal energy which can be used to generate electricity has side effects too. It can bring toxic chemicals beneath the earth surface onto the top and can create environmental changes.

Non-renewable energy:

Renewable energy is energy which is taken from the sources that are available on the earth in limited quantity and will vanish fifty-sixty years from now. Non-renewable sources are not environmental friendly and can have serious affect on our health. They are called non-renewable because they can be re-generated within a short span of time. Non-renewable sources exist in the form of fossil fuels, natural gas, oil and coal.

4.2: CONCEPT OF WIND ENERGY:

4.2.1: INTRODUCTION:

Wind energy is nothing but the velocity by which the air flows. It is of kinetic energy; now days we are using wind mills to generate electrical power. A windmill is a machine which converts the energy of wind into rotational energy by means of vanes called sails or blades. Originally windmills were developed for milling grain for food production. In the course of history the windmill was adapted to many other industrial uses. An important application was to pump water. Windmills used for generating electricity are commonly known as wind turbines.

4.2.2: NEED OF WIND MILLS IN PRESENT GENERATION:

The development of wind power in India began in the 1990s, and has significantly increased in the last few years. Although a relative newcomer to the wind industry compared with Denmark or the US, India has the fifth largest installed wind power capacity in the world.

In 2009-10 India's growth rate was highest among the other top four countries. The worldwide installed capacity of wind power reached 197 GW by the end of 2010. China (44,733 MW), US (40,180 MW), Germany (27,215 MW) and Spain (20,676 MW) are ahead of India in fifth position. The short gestation periods for installing wind turbines, and the increasing reliability and performance of wind energy machines has made wind power a favored choice for capacity addition in India. Suzlon, as Indian-owned Company, emerged on the global scene in the past decade, and by 2006 had captured almost 7.7 percent of market share in global wind turbine sales. Suzlon is currently the leading manufacturer of wind turbines for the Indian market, holding some 52 percent of market share in India. Suzlon's success has made India the developing country leader in advanced wind turbine technology

4.2.3: different types of wind mills:

4.3: FUEL CELL:

4.3.1 INTRODUCTION:

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.

4.3.2 DESIGN FEATURES IN A FUEL CELL ARE:

- The electrolyte substance. The electrolyte substance usually defines the type of fuel cell.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, which breaks down the fuel into electrons and ions. The anode catalyst is usually made up of very fine platinum powder.
- The cathode catalyst, which turns the ions into the waste chemicals like water or carbon dioxide. The cathode catalyst is often made up of nickel.

4.3.3: TYPES OF FUEL CELLS:

PROTON EXCHANGE FUEL CELLS:

In the archetypal hydrogen-oxygen proton exchange membrane fuel cell (PEMFC) design,

a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides. This was called a "solid polymer electrolyte fuel cell" (SPEFC) in the early 1970s, before the proton exchange mechanism was well-understood. (Notice that "polymer electrolyte membrane" and "proton exchange mechanism" result in the same acronym.) On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what is commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water.

PROTON EXCHANGE MEMBRANE FUEL CELL DESIGN ISSUES:

Water and air management (in PEMFCs). In this type of fuel cell, the membrane must be hydrated, requiring water to be evaporated at precisely the same rate that it is produced. If water is evaporated too quickly, the membrane dries, resistance across it increases, and eventually it will crack, creating a gas "short circuit" where hydrogen and oxygen combine directly, generating heat that will damage the fuel cell.

HIGH TEMPERATURE FUEL CELLS: A SOLID OXIDE FUEL CELL:

A solid oxide fuel cell (SOFC) is extremely advantageous "because of a possibility of using a wide variety of fuel" [1]. Unlike most other fuel cells which only use hydrogen, SOFCs can run on hydrogen, butane, methanol, and other petroleum products. The different fuels each have their own chemistry. For methanol fuel cells, on the anode side, a catalyst breaks methanol and water down to form carbon dioxide, hydrogen ions, and free electrons. The hydrogen ions move across the electrolyte to the cathode side, where they react with oxygen to create water. A load connected externally between the anode and cathode completes the electrical circuit. Below are the chemical equations for the reaction:

Anode Reaction: $\text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + 6\text{H}^+ + 6\text{e}^-$

Cathode Reaction: $\frac{3}{2} \text{O}_2 + 6\text{H}^+ + 6\text{e}^- \rightarrow 3\text{H}_2\text{O}$

Overall Reaction: $\text{CH}_3\text{OH} + 3/2 \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
+ electrical energy
MCFC: Molten-carbonate fuel cells (MCFCs) are high-temperature fuel cells, that operate at temperatures of 600°C and above.

PROPOSED APPLICATION:

Introduction:

THE increase in global energy demand, air pollution, global warming, and the rapid evaporation of fossil fuel has made it necessary to look toward renewable sources as a future energy solution. However, the higher penetration level of these intermittent renewable energy sources (RESs) poses a great threat to network security. Therefore, the RESs are required to comply with strict technical and regulatory frameworks to ensure the safe, reliable, and efficient operation of the overall network. With the advancement in power electronics and digital control technology, the RES can now be actively controlled to enhance the system stability with an improved power quality at the point of common coupling (PCC).

System Configuration And Control:

The system under consideration with control description is shown in Fig. 1, where a RES is connected on the dc link of a grid-interfacing four-leg inverter. The fourth leg of the inverter is utilized to compensate the neutral current of 3P4W network. Here, the inverter is a key element since it delivers the power from renewable to grid and also solves the power quality problem arising due to unbalanced nonlinear load at PCC. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter-injected power appears as balanced resistive load to the grid, resulting into the UPF grid operation.

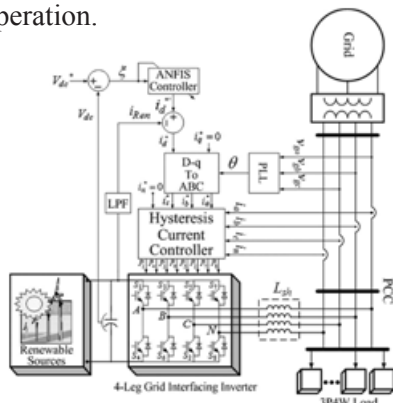


Fig. 6.1. Schematic and control description of proposed renewable-based distributed generation system.

Design of adaptive neuro-fuzzy controller:

An optimized adaptive-network-based fuzzy inference system (ANFIS) having a 1:3:3:3:1 architecture is generated from the initial data using MATLAB/anfiseditor as shown in Fig. 2. This Takagi-Sugeno-Kang fuzzy model-based ANFIS architecture has one input and one output, which is further tuned online using the error back propagation method as shown in Fig. 3. The error between reference dc-link voltage and actual dc-link voltage ($\xi = V_{dc} - V_{dc}$) is given to the neuro-fuzzy controller, and the same error is used to tune the precondition and consequent parameters. The control of dc-link voltage gives the active power current component (i_d), which is further modified to take into account the active current component injected from RES (i_{Ren}).

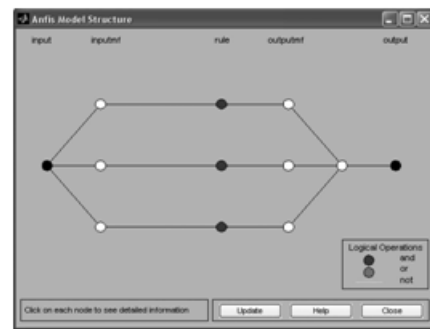


Fig. 6.2: Optimized ANFIS architecture suggested by MATLAB/anfis editor.

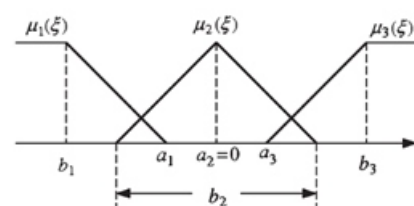


Fig. 4. Fuzzy membership functions. Member ship functions are assigned to each input. The trapezoidal and triangular membership functions are used to reduce the computation burden as shown in Fig. 4, and their corresponding node equations are given as follows: where the value of the parameters $\{a_i, b_i\}$ changes with the change in error and accordingly generates the linguistic value of each membership function. Parameters in this layer are referred as premise parameters or precondition parameters. Layer 2: Every node in this layer is a circle labeled as Π which multiplies the incoming signals and forwards it to the next layer $O_i = \mu_i \cdot f_i = \mu_{i_a1} \cdot \xi$, $i = 1, 2, 3$ (6) Where the parameters $\{a_{i0}, a_{i1}\}$ are tuned as the function of the input (ξ). The parameters in this layer are also referred as consequent parameters.

Layer 5: This layer is also called the output layer which computes the output as given in the following:

$$Y = \mu_1 \cdot f_1 + \mu_2 \cdot f_2 + \mu_3 \cdot f_3. \quad (7)$$

The output from this layer is multiplied with the normalizing factor to obtain the active power current component (i_d).

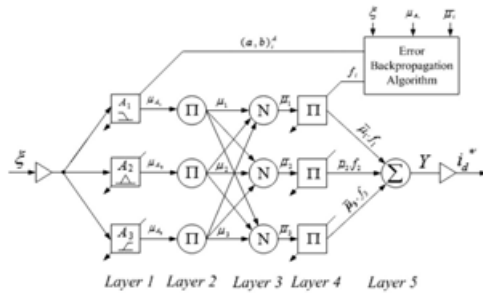


Fig. 6.3: Schematic of the proposed ANFIS-based control architecture.

SIMULATION RESULTS:

An extensive simulation study has been carried out for the renewable interfacing inverter in order to verify the proposed control strategy. The system under consideration is simulated using the Sim Power System tool box of MATLAB/Simu link. An IGBT-based four-leg current-controlled voltage source inverter is actively controlled to achieve the balanced sinusoidal grid currents at UPF despite the highly unbalanced nonlinear load at the PCC under varying renewable generating conditions. A RES with variable output power is connected on the dc link of the grid-interfacing inverter.

7.2 EXPERIMENTAL RESULTS:

The proposed adaptive neuro-fuzzy controller is implemented in real time on a four-leg IGBT-based inverter Fig. 6. Simulation results: Phase grid voltage, grid current, load current, inverter current, load neutral current, and inverter neutral current. Fig. 7. Simulation results. (a) Phase a grid voltage and current. (b) Load current. (c) Inverter current. ing digital signal processing and control engineering DS1104, Whereas the RES is emulated with an auxiliary inverter connected on a dc link. It takes a sampling time of 75 μ s to realize the proposed ANFIS controller in real time. The 3P4W nonlinear load is composed of three-phase nonlinear RL load, one-phase RL nonlinear load connected in between phase a and neutral, and a single-phase RL load in between phase b and neutral.

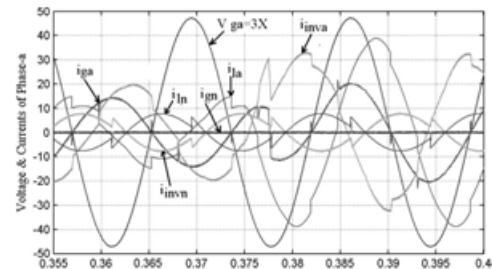


Fig.7.2: Simulation results: Phase a grid voltage, grid current, load current, inverter current, load neutral current, and inverter neutral current.

The inverter operation is mainly divided into two parts: active filter operation and renewable interfacing operation. All the experimental results are captured with an oscilloscope in real time as shown in Figs. 8–10.

7.2.1 ACTIVE FILTER OPERATION:

Filtering capabilities of the inverter are demonstrated. In Fig. 8(a), the traces of 3P4W grid currents are shown before and after compensation. Initially, the grid supplies an unbalanced nonlinear load current with a high neutral current, which is highly undesirable. In order to compensate this unbalanced nonlinear current, the inverter currents are injected in such a way that the combination of load and inverter current appears as a balanced set of fundamental currents. The traces of the injected inverter currents are shown in Fig. 8(b), just before and after compensation.

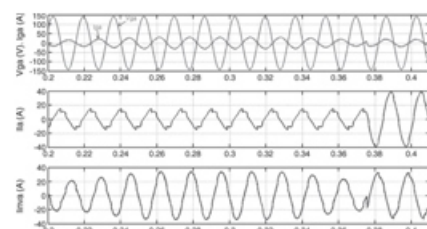


Fig. 7.3: Simulation results. (a) Phase a grid voltage and current. (b) Load current. (c) Inverter current.

Here, it can be easily noticed that the grid currents are perfectly balanced with a sinusoidal profile. Moreover, the inverter is Fig. 8. Experimental results: (a) Grid currents and (b) inverter currents, just before and after compensation. Successfully able to supply the load neutral current demand locally, as evident from the zero value of the grid neutral current (i_{gn}).

7.2.2 RENEWABLE INTERFACING OPERATION:

In this mode of operation, the bidirectional power flow capabilities of the renewable interfacing inverter are discussed. Here, the main objective is not only the grid interfacing of the renewable but also to compensate the 3P4W nonlinear unbalanced load at PCC simultaneously. The inverter supplies the renewable injected current and the nonlinear unbalanced component of load current. This enables the grid to always supply/absorb only the balanced set of currents at UPF.

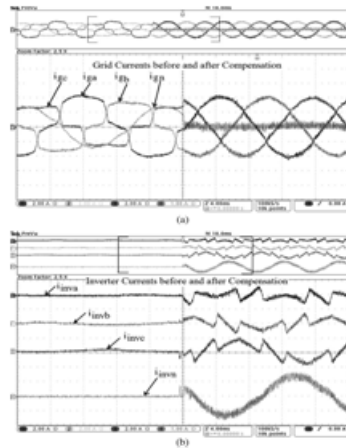


Fig. 7.4: Experimental results: (a) Grid currents and (b) inverter currents, just before and after compensation.

In this mode of operation, only the active Here, it can be noticed that the grid current is highly unbalanced with the UFs of 20.48%, 0.41%, and 21.07% in phase a, phase b, and phase c, respectively, resulting into the flow of a 1.1-A current in neutral wire. The percent THDs present in phase a, phase b, and phase c currents are 14.7%, 18.2%, and 23.2%, respectively. However, once after the interconnection of the renewable interfacing inverter, the grid currents become almost balanced and harmonic free with a very low UF of 0.7%, a very low level of THDs of 2.9%, and an almost zero current in grid side interfacing mode of operation. neutral wire.

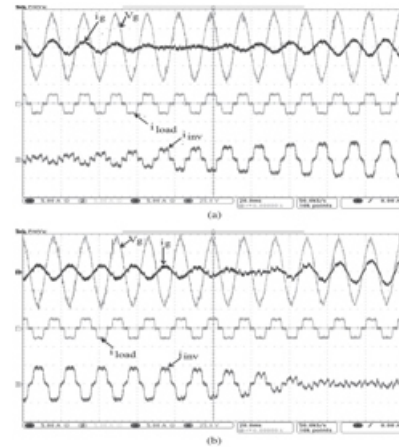


Fig. 7.5: Experimental results: Inverter performance under the renewable interfacing mode of operation.

II. SYSTEM CONFIGURATION AND CONTROL:

The system under consideration with control description is shown in Fig. 1, where a RES is connected on the dc link of a grid-interfacing four-leg inverter.

Power Factor Correction Capacitors:

Power factor correction capacitors and harmonic filters are an essential part of modern electric power systems.

Harmonic Filtering:

As the world becomes more dependent on electric and electronic equipment, the likelihood that the negative impact of harmonic distortion increases dramatically. The efficiency and productivity gains from these increasingly sophisticated pieces of equipment have a negative side effect...increased harmonic distortion in the power lines. The difficult thing about harmonic distortion is determining the cause. Once this has been determined, the solution can be easy.

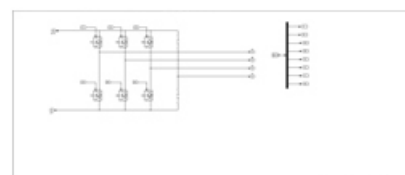


Fig. 4: 4-leg inverter in which one leg is replaced with capacitor.

INVERTER PERFORMANCE AS A COMPENSATING DEVICE:

It can be noticed that the dc-link voltage is almost constant irrespective of any kind of variation in injected inverter current. A comparative table showing the total harmonic distortions (THDs) and unbalance factor (UF) before and after compensation is given in Table I, where the percentage UF is calculated separately for each phase using $\%UF_{abc} = \frac{|i_{abc} - i_{avg}|}{i_{avg}} \cdot 100$. (8) Here, it can be noticed that the grid current is highly unbalanced with the UFs of 20.48%, 0.41%, and 21.07% in phase a, phase b, and phase c, respectively, resulting into the flow of a 1.1-A current in neutral wire.

EXTENSION TO THE EXISTING APPLICATION:

In electric power distribution, capacitors are used for power factor correction. Such capacitors often come as three capacitors connected as a three phase load. Usually, the values of these capacitors are given not in farads but rather as a reactive power in volt-amperes reactive (VAR). The purpose is to counteract inductive loading from devices like electric motors and transmission lines to make the load appear to be mostly resistive. Individual motor or lamp loads may have capacitors for power factor correction, or larger sets of capacitors (usually with automatic switching devices) may be installed at a load center within a building or in a large utility substation.

V. CONCLUSION:

This paper has presented a novel adaptive neuro-fuzzy control algorithm for the renewable interfacing inverter. The controller works satisfactorily under the dynamic operating conditions. It has also been shown that the inverter is able to perform all the duties of the shunt APF while maintaining the smooth bidirectional power flow simultaneously. The simulation results supported by the experimental results are provided to validate the fact that the renewable interfacing inverter can act as a multi operation device in order to utilize its maximum rating. Power factor correction capacitors are the simplest and most economical means of increasing the capacity of any power system, minimizing energy losses and correcting load power factor. In addition, power factor penalties can be reduced and power quality can be greatly enhanced.

REFERENCES:

- [1] M. Singh and A. Chandra, "Power maximization and voltage sag/swell ride-through capability of PMSG based variable speed wind energy conversion system," in Proc. 34th IEEE IECON/IECON, Orlando, FL, 2008.
- [2] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006.
- [3] X. Guo, W. Wu, and Z. Chen, "Multiple-complex coefficient-filter-based phase-locked loop and synchronization technique for three-phase grid interfaced converters in distributed utility networks," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1194–1204, Apr. 2011.
- [4] P. Jintakosonwitt, H. Akagi, H. Fujita, and S. Ogasawara, "Implementation and performance of automatic gain adjustment in a shunt-active filter for harmonic damping throughout a power distribution system," IEEE Trans. Power Electron., vol. 17, no. 3, pp. 438–447, May 2002.