International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 1

An Analysis and Modeling of Grid Connected Multiple-Pole Multilevel Unity Power Factor Rectifier

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ABSTRACT

In this paper, to improve power factor a simple model based on five levels multiple pole is used. It is also used to improve harmonic distortion and efficiency which is done by using reduced number of component counts. Most of the work has been done to obtain these factors. In this project, 5L-M2UPFR is used which give almost unity power factor. By this method, the unity power factor with input current shaping is obtained with less number of measurement components. This paper uses balanced and unbalanced load condition over which these improved response is obtained.

***Keywords**: Vienna Rectifier, 5L-M2UPFR, Power factor, average current control (ACC), Electrical Grid*

INTRODUCTION

To obtain the power through the source such as nuclear reactors, fossil fuel as well as hydroelectricity plants are used. These plants can regularly generate electricity of some hundred million watts (MW). Transmission is based on the network over which the electrical power gets transmitted. This process includes various nodes, substations, cables etc. The distribution is based on the requirement of the consumers. At this stage, the as per the requirement by the users the power gets reduced from high voltage to the low voltage, i.e. step down the voltage as per the consumers. At this stage, the power is used by the user in various purposes, i.e. household purpose and the industrial use etc. The power grid includes producing stations that produce electric strength, high-voltage transmission strains that carry strength from distant assets to call for facilities, and distribution strains that connect person customers [2]. The smart grid is electricity networks which are two way digital communications exist between supplier and consumer [3]. The smart grid effectively integrate all the activities of the user whom are connected to them i.e. generators, consumers those that do both, to get efficient, sustainable power with high quality, low losses and security with supply and safety [4]. The smart grid is smarter networks, both in transmission and distribution domains. This will obtain a whole range of new and specific technologies which improves the transmission system. Besides this, it places new requirements on the automation, monitoring control and protection of distribution substations and transformer station. The verbal exchange infrastructures are not the best source of vulnerabilities. Software and hardware used for building the smart grid infrastructure are liable to being tampered with even before they're linked collectively. Rogue code, including the so-known as common sense bombs which cause sudden malfunctions that may be inserted into software while it's far being advanced. As for hardware, remotely operated "kill switches" and hidden "backdoors" may be written into the chips of computer used by the smart grid and permitting outdoor actors to manipulate the structures. The threat of compromise in the production manner could be very real and is perhaps the least understood hazard. Tampering is sort of impossible to stumble on and even tougher to eliminate. Power stations may be placed near a gasoline supply, at a dam site, or to take advantage of renewable strength assets, and are frequently positioned away from closely populated areas. Multilevel converters have become greater appealing for lots industry and academia research. Most of the commercially to be had multilevel inverters require a bulky section-shifted transformer with multiple bridge rectifiers linked at the front-stop aspect [2,5]. However, the quantity and the load of such configuration are large and heavy. In addition, more losses are skilled in the transformer during low utilization because of its middle resistance [6, 7]. Several new transformers less multilevel rectifier topologies with low switching frequency operation had been reported in the literature. The referred to low-cost topologies have performed accurate performance and additionally confirmed that the clear out length may be extensively reduced in spite of the low switching frequency operation. However, each of those topologies has its limitations and disadvantages. For example, a complex manipulate algorithm is needed to stability the flying capacitors of the three-section megastar-configured PUC topology. While in the case of RPC-DCR topology, simplest two switches are decreased in each phase-leg however the general aspect counts are not notably optimized. Hence, large wide variety of gate drivers and remote gate supplies are still required. Thus, a decrease cost solution is finished with the discount of measurement sensors needed for the remarks manage loop not like the proposed switching method provided in [8]. In addition to that, top notch dynamic reaction is demonstrated with the expected performances of both grid voltage and load modern-day during unbalanced grid condition.

Multilevel converters are becoming more attractive for many industry and academia research. Most of the commercially available multilevel inverters require a bulky phase-shifted transformer with multiple-bridge rectifiers connected at the front-end side [2, 5]. However, the volume and the weight of such configuration are large and heavy. In addition, more losses are experienced in the transformer during low utilization due to its core resistance [6, 7]. Several new transformers less multilevel rectifier topologies with low switching frequency operation have been reported in the literature.

Recent developments on high incremental voltage level rectifier topologies with reduced number of components are found namely: (i) packed U cells multilevel converter (PUC) [22], (ii) reduced-part count diode-clamped rectifier (RPC-DCR) [23] and (iii) hybrid diode-clamped and flying capacitor rectifier (DCLP-FC) [24]. The mentioned low-cost topologies have achieved good efficiency and also proven that the filter size can be drastically reduced even with the low switching frequency operation. However, each of these topologies has its limitations and disadvantages. For instance, a complex control algorithm is required to balance the flying capacitors of the three-phase star-configured PUC topology. While in the case of RPC-DCR topology, only two switches are reduced in each phase-leg but the total component counts are not significantly optimized.

Electrical Grid

An electrical grid is an interconnected network designed to deliver electrical energy from distributors to consumers. It consists of the power generation stations which produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers [2]. Power stations may be positioned near a fuel supply, at a dam website, or to take advantage of renewable electricity resources, and are often located far away from closely populated regions. They are usually quite large to take advantage of the economies of scale. The electrically powered electricity that is generated is stepped as much as a better voltage at which it connects to the electrical power transmission network.

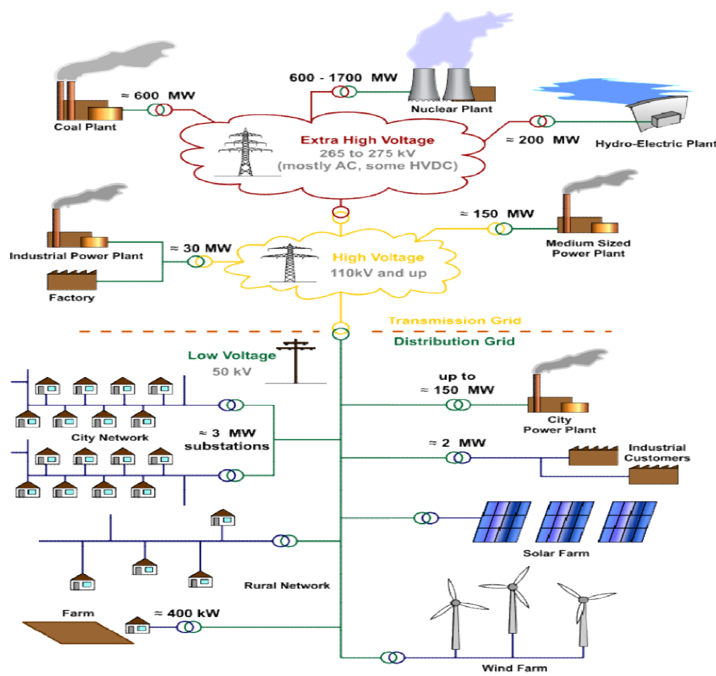

Fig 1.1: Electrical Grid

The bulk electricity transmission network will pass the power long distances, occasionally throughout global boundaries, until it reaches its wholesale customer (commonly the organization that owns the local electric strength distribution network). On arrival at a substation, the power will be stepped down from a transmission level voltage to a distribution degree voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the provider place, the strength is stepped down once more from the distribution voltage to the specified provider voltage.

Objective

To design a cost effective transformer less multiple pole unity power factor rectifier. The proposed three phases M^2UPFR utilized only six switched to synthesize a five level input phase voltage stepped waveform, Hence the component counts are greatly reduced. A low switching frequency operation with the average current control (ACC) technique is implemented for the grid current harmonic compensation.

Problem Statement

From the analysis of various work has already been done it has been found that there are number of problems associated with these works i.e. the model is bulky because of size of the transformer, the losses of the switching are also dominant which occurs at very high frequency. The effect the output power, power factors, efficiency, total harmonic distortions etc.

Rectifier

A rectifier is an electrical tool that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in one direction. The process is called rectification. Physically, rectifiers take some of the forms, which include vacuum tube diodes, mercury arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-managed rectifiers and different silicon-based totally semiconductor switches. Historically, even synchronous electromechanical switches and motors were used. Early radio receivers, known as crystal radios, used a "cat's whisker" of first-rate twine pressing on a crystal of galena (lead sulfide) to serve as a point-touch rectifier or "crystal detector". Rectifiers have many uses, however, are often found serving as additives of DC energy resources and excessive direct current power transmission systems.

Three-Phase Rectifiers

3-phase AC input, half- and full-wave rectified DC output waveforms Single-phase rectifiers are commonly used for power supplies for domestic equipment. However, for most industrial and high-power applications, three-phase rectifier circuits are the norm. As with single-phase rectifiers, three-phase rectifiers can take the form of a half-wave circuit, a full-wave circuit using a center-tapped transformer, or a full-wave bridge circuit. Thyristors are commonly used in place of diodes to create a circuit that can regulate the output voltage. Many devices that provide direct current actually generate three-phase AC. For example, an automobile alternator contains six diodes, which function as a full-wave rectifier for battery charging. Three-phase, half-wave circuit An uncontrolled three-phase, half-wave circuit requires three diodes, one connected to each phase. This is the simplest type of three-phase rectifier but suffers from relatively high harmonic distortion on both the AC and DC connections. This type of rectifier is said to have a pulse-number of three, since the output voltage on the DC side contains three distinct pulses per cycle of the grid frequency.

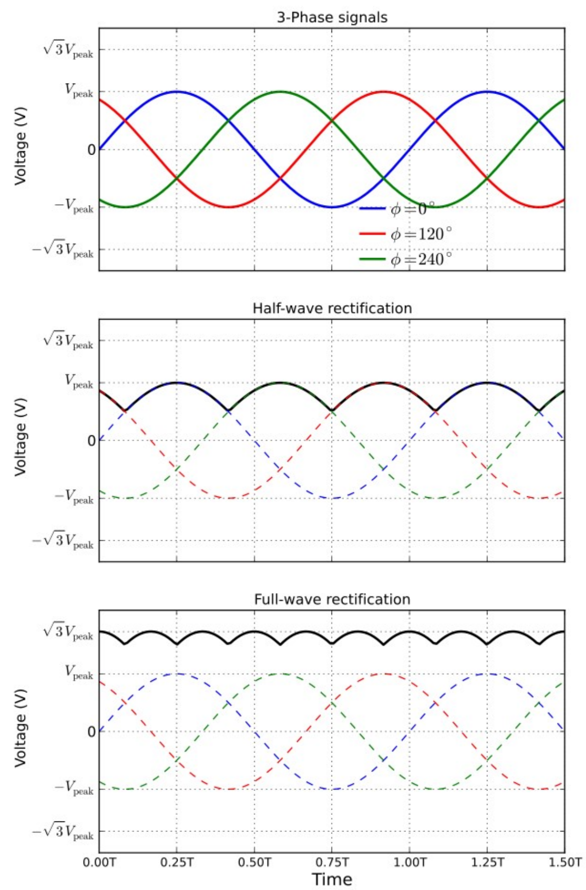

Fig 4.3: output voltage on the DC side contains three distinct pulses per cycle

Three-phase, full-wave circuit using center-tapped transformer If the AC supply is fed via a transformer with a center tap, a rectifier circuit with improved harmonic performance can be obtained. This rectifier now requires six diodes, one connected to each end of each transformer secondary winding. This circuit has a pulse-number of six, and in effect, can be thought of as a six-phase, half-wave circuit. Before solid state devices became available, the half-wave circuit, and the full-wave circuit using a center-tapped transformer were very commonly used in industrial rectifiers using mercury-arc valves [7]. This was because the three or six AC supply inputs could be fed to a corresponding number of anode electrodes on a single tank, sharing a common cathode. With the advent of diodes and thyristors, these circuits have become less popular and the three-phase bridge circuit has become the most common circuit.

Motor-Generator

Motor-generator and Rotary converter A small motor-generator set A motor-generator set, or the similar rotary converter, is not strictly a rectifier as it does not actually rectify current, but rather generates DC from an AC source. In an "M-G set", the shaft of an AC motor is mechanically coupled to that of a DC generator.

The DC generator produces multiphase alternating currents in its armature windings, which a commutator on the armature shaft converts into a direct current output; or a homopolar generator produces a direct current without the need for a commutator. M-G sets are useful for producing DC for railway traction motors, industrial motors and other high-current applications, and were common in many high-power D.C. uses (for example, carbon-arc lamp projectors for outdoor theaters) before high-power semiconductors became widely available.

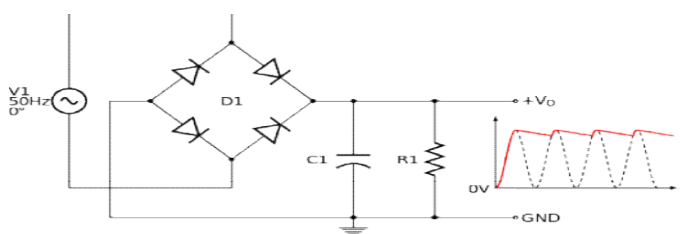

Fig 4.4: RC-Filter Rectifier

Vienna Rectifier

The Vienna Rectifier is a pulse-width modulation rectifier, invented in 1993 by Johann W. Kolar. It provides:

Three-phase three-level three-switch PWM rectifier with controlled output voltage

- Three-wire input, no connection to neutral.
- Ohmic mains behaviour[citation needed]
- Boost system (continuous input current).
- Unidirectional power flow.
- High power density.
- Low conducted common-mode EMI emissions.
- Simple control to stabilize the neutral point potential.
- Low complexity, low realization effort
- Low switching losses.
- Reliable behaviour (guaranteeing ohmic mains behaviour) under heavily unbalanced mains voltages and in case of mains failure.

Power Factor

The power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit,[2][5] and is a dimensionless number in the closed interval of −1 to 1. A power factor of less than one means that the voltage and current waveforms are not in phase, reducing the instantaneous product of the two waveforms (V × I). Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.

A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source, which is normally considered the generator [6] [7] [22]. In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. Linear loads with low power factor (such as induction motors) can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor. The devices for correction of the power factor may be at a central substation, spread out over a distribution system, or built into power-consuming equipment.

MULTIPLE-POLE UNITY POWER FACTOR RECTIFIER TOPOLOGY

Basic Operating Principle

A multiple-pole unity power factor rectifier topology with balanced load which is shown in Figure 2 is built on the basis of three-level VIENNA rectifier cells in each phase-leg. The concept of inverter which is similar to multiple-pole structure is used in multilevel diode circuit [9]. Hence, the output terminals of both the circuit, i.e. VIENNA rectifier cells which are linked to the respective dc capacitors with resource of balancing circuit [10, 11]. The overall performance of this method is synthesized which is based on switching state selection and the direction of phase current in which each cell is characterized with the multiple level input voltage stepped waveform.

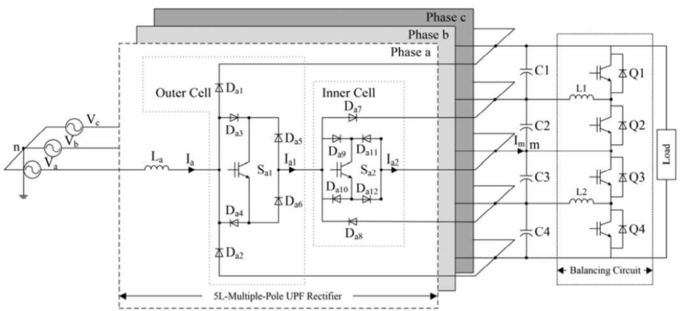

Figure 2: Unidirectional 5L-M2UPFR with the balancing circuit

Controller Design

Unity Power Factor Control

The load current and grid voltage is controlled by using the power factor control as shown in figure 3. The controller structure is constructed using synchronous reference frame (SRF) current control [12]. To limit the control bandwidth, the complicated phase locked loop design is used in the transformation.

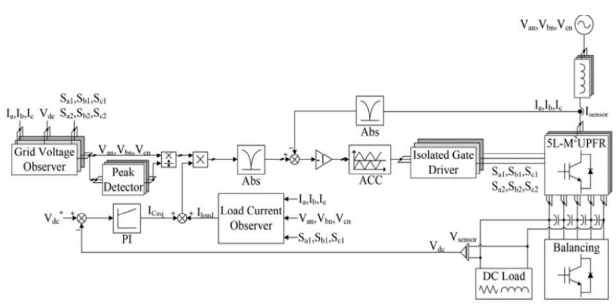

Figure 3: Block diagram of the unity power factor controller with the grid voltage and load current observers.

On this basis of the electrical control system there are two types of control is used i.e. voltage and current control. These two control mechanism is applied to both the circuits i.e. at outer loop and at the inner loop. The voltage control carried at the outer loop and current control carried at the inner loop [9]. The dc equivalent capacitor current is calculated by the outer loop control which regulates the output dc link voltage. Meanwhile, the load current is formulated from the power balanced principle.

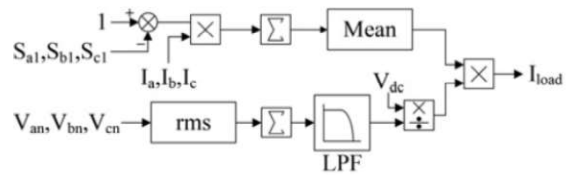

Figure 4: The Load current observer

Voltage Control

The voltage control carried at the outer loop is regulated with a the proportional integral (PI) controller which is expressed as follows

$$I_{Ceq} = K_p \frac{\tau_i s + 1}{\tau_i s}\left[V_{dc}^{*}(t) - V_{dc}(t)\right]$$

Where,

K_p represents the proportional gain of the dc-link voltage regulator

t_i represents the settling time of the dc-link voltage tracking.

The approximated value of the proportional gain (K_p) is obtained from the energy storage model. According to stability criteria, the proportional gain of the control system expressed in below equation.

$$K_p = \frac{3V_m \tau_i}{2V_{dc} C_{eq} P_o}$$

Current Control

The grid current control technique of the active rectifier which are carried out by inner loop circuit is classified into four categories, these are space vector modulation (SVM) [13, 14], fix hysteresis band current control (FHBCC) [12, 15], variable hysteresis band current control [16] and ACC [15, 17]. The SVM scheme uses high computational effort; this is due to complex sector control algorithm which is required for the higher voltage stepped level rectifier topology [18]. Both the problem associated with HBCC and ACC can be overcome by using SVM scheme. However, The circuit of FHBCC scheme exhibits very complex circuits, which is the only disadvantage of this variable switching frequency which also increase the complexity of the design of the input inductance filter.

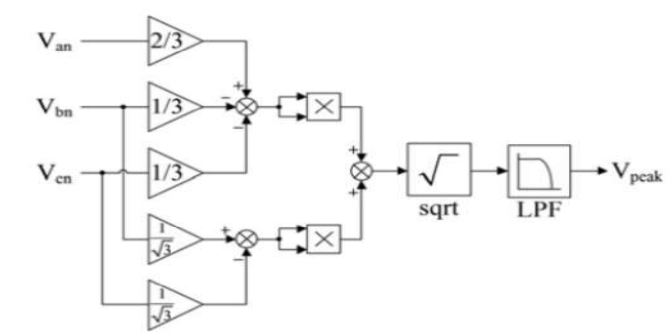

Figure 5: Energy stored model

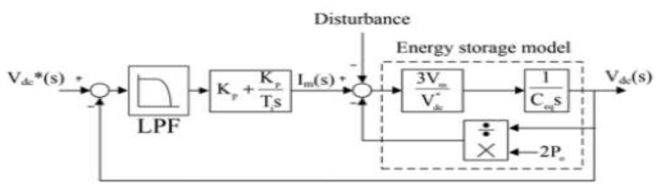

Figure 6: Peak detector of the grid voltage for the reference sinusoidal wave

Grid Voltage

For the proper rectifier configurations various observer strategies had already been proposed [19-21]. Besides these benefit of disposing of the sensors which are needed, this approach reduces the converter size and also offers a lower production cost as well. This simple model will eliminate the problem of 3 levels multiple pole which is total harmonic distortion. To derive and find the ac and dc voltages, the statistics of three phase grid currents are sufficient, but very high dc-link voltage ripples are experienced throughout the computational process. Hence, high cutting edge total harmonic distortion inside the grid is inflicting.

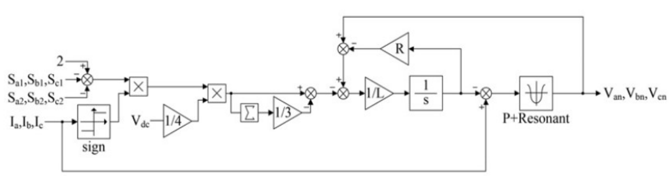

Figure 7: Grid voltage observer

CONCLUSION

This proposed topology, i.e. 5 level 5L-M2UPFR method provides very high reliability over the three phase power supply at extreme unbalanced condition of grid. These three conditions will help in the design of the method by which we can obtain the system with reduced number of sensors which improves the failures of the system and by this method almost unity power factor with very less total harmonics distortion (THD) is obtained. Due to less number of sensors, the components count also gets reduced. Most important is that we can design light weight and high power density using this method.

ACKNOWLEDGEMENT

Expression of giving thanks are just a part of those feeling which are too large for words, but shall remain as memories of wonderful people with whom I have got the pleasure of working during the completion of this work. I would like to express my deep and sincere gratitude to my supervisor, Mr. Umashankar Patel, Assistant Professor in Department of Electrical & Electronics Engineering, DIMAT, Raipur. His wide knowledge and his logical way of thinking have been of great value for me. His/her understanding, encouraging and personal guidance have provided a good basis for the present work. I am grateful to DIMAT, Raipur (C.G.) which helped me to complete my work by giving encouraging environment.

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