EVALUATING THE PERFORMANCE OF A SEVEN-LEVEL REDUCED SWITCH AND AN RBFNN-BASED HARMONIC CURRENT GENERATOR IN A SWITCHED ACTIVE POWER FILTER

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ABSTRACT

One of the most significant problems a power system might encounter is a disruption in Power Quality (PQ), which is mostly caused by non-linear loads. Harmonics are one of the most important PQ disturbances, and they should be reduced in addition to reactive power correction. The Shunt Active Power Filter (SAPF) in this study is a modified seven-level boost Active-Neutral-Point-Clamped (7LB-ANPC) inverter. Maintaining the link voltage across the capacitor is another crucial component of this study, and it is achieved by using a PI controller that has been adjusted using an Adaptive NeuroFuzzy Inference System (ANFIS). In order to extract the reference current, an adaptive instantaneous p-q theory is initiated, and a Radial Basis Function Neural Network (RBFNN) is used to extract the harmonics. In order to reduce current harmonics using reactive power compensation, the opposite harmonics are injected into the Point of Common Coupling (PCC) via the gating sequence of the inverter, which is constructed for the outputs obtained from ANFIS and RBFNN.

With fewer switching devices and better boosting capabilities, the 7Lb-ANPC inverter provides minimal switching losses. A THD of 0.89% for the source current is obtained by RBFNN-based reference current generation. The suggested approach is implemented in hardware using an FPGA Spartan 6E and simulated using MATLAB.

Index Terms: Radial Basis Function Neural Network, Shunt Active Power Filter, Multi-Level Inverters, Active Neutral Point Clamped Inverter, Adaptive Neuro-Fuzzy Inference System.

1.INTRODUCTION

Non-linear loads are the main source of various power system disruptions that have an impact on the quality of electricity in residential and commercial applications. Among other power quality (PQ) problems, harmonics have disrupted the system's overall performance. These harmonics are mostly caused by power electronic devices, SMPS, and other similar devices. Resolving these harmonics involves addressing the root of the issue. FACTS devices are used to adjust for PQ issues such as sag, swell, flickers, harmonics, and current imbalances. Active or passive filters are used to reduce the current harmonics in the PCC; however, because of their resonance and fixed compensation, passive filters are not recommended.

Therefore, a dynamic and adaptable solution that opens the door for the creation of active filters is required. Both this study and the literature reviews on SAPF use shunt active power filters, or SAPFs. The SAPF with cascade controller, which is covered in, is used to reduce harmonics and rectify power factor. To accomplish harmonic current compensation, a filter is developed using a 1φ transformer and a three-phase bridge integration. As mentioned in, SAPF is built using SRF controllers based on Park's transformation, which generates an accurate reference current for a quicker reaction. The design of a hybrid filter for a four-wire three-phase system, which is covered in [10], eliminates series and shunt resonant issues.

In order to improve the voltage quality, a compensating method for the optimum control of SAPF is described in. SAPF is applied in order to lower the PQ difficulties, and a recursive inverse-based control control algorithm is used in this case. The SAPF's gating sequence is managed using a modified recursive algorithm, which helps to reduce power quality issues. For the shunt active filters, an appropriate power circuit must be used to lower the harmonic content, and a multi-level inverter (MLI) is the ideal option for this. The MLI categories with the greatest number of switches but the highest cost and lowest efficiency are flying capacitor, diode clamped, and cascading H-bridge. Additionally, these MLIs provide a greater range of voltage levels with less THD and electromagnetic interference. This work uses a modified seven-level boost active-neutral-point clamped (7LB-ANPC) inverter, which reduces the amount of power electronic components without the need for additional capacitors. The literature provides an overview of several current approaches. By combining the three-level diode neutral point clamped circuit, which also retains the capacitor voltage, and the twin T-type converters, a simpler model is produced. A novel approach to seven-level ANPC is presented, which eliminates the issue of phase voltage jumping and dynamic voltage balancing. An H-bridge and T-type converter hybrid is shown, with space vector modulation added to increase the modulation index intended for floating capacitor voltage management.

A self-voltage balancing architecture is presented in order to achieve good voltage quality while using the fewest possible switching components. A cascaded form of multilayer inverter is presented with fewer switching components and more levels and better power quality. Utilizing the three sources and eight switches, level eleven is reached. With two distinct topologies, additional voltage levels may be achieved. Additionally, more voltage sources can be added to get more levels with fewer switching devices. Using eight switches and three voltage sources yields the greatest efficiency of 98.5 percent, with a voltage level of 13. The thorough examination of power loss is completed in. With the aid of two voltage sources and eleven switches, an 11-level voltage based on switched capacitors is produced. Also, a SHE-PWM approach is used to enhance this topology's performance. Here, a modified seven-level inverter is shown, which reduces switching losses with strong boosting capacity by limiting the number of switches and DC sources employed. This is achieved by analyzating all the known 7L inverter topologies. Shunt filters are only really useful when an appropriate theory is put into practice to extract the reference current.

This study realizes an adaptive instantaneous p-q theory, and the literature surveys have clarified how different theories are used. The analysis of Fryze current extraction and instantaneous reactive power theory occurs during the creation of reference current, which reduces harmonics and improves power quality. SRF theory is used to extract reference currents. Park's transformation is used to extract the reference current, which produces a quick dynamic response. The shunt converter rectifies the PQ issues on the source side in addition to the current harmonics that were produced on the load side. A control algorithm is also included for the purpose of producing the reference signal. The capacitor's link voltage, which must be maintained and is accomplished by utilizing the PI controller, is another important consideration. The capacitor voltage is kept constant by the PI controller, resulting in minimal harmonic distortion and a high switching frequency. Using the PI controller, the link voltage across the capacitor has been maintained at this point, and a control technique is suggested for extracting the harmonics. This is accomplished in this study by employing a tuned PI controller with ANFIS, whose performance is compared to that of a fuzzy logic controller. In this study, a modified seven-level boost ANPC inverter is used to mitigate harmonics. Radial Basis Function Neural Network (RBFNN) with adaptive instantaneous p-q theory is used to extract reference current. Moreover, the PI controller maintains the link voltage in the capacitor, and it uses the Fuzzy-analogous Adaptive Neuro-Fuzzy Inference System (ANFIS) to adjust the PI controller's settings.

2. POWER QUALITY

Like many other business sectors, the container crane industry of today is often mesmerized by the bells and whistles, vibrant diagnostic displays, high speed performance, and degrees of automation that may be attained. While these characteristics and their associated computer-based improvements are essential for a smooth terminal operation, we also need toLike many other business sectors, the container crane industry of today is often mesmerized by the bells and whistles, vibrant diagnostic displays, high speed performance, and degrees of automation that may be attained. We must remember the foundation upon which we are constructing even if these capabilities and their indirectly linked computer-based innovations are essential to an effective terminal operation. keep in mind the base upon which we are constructing.

2.1 POWER QUALITY PROBLEMS:

Power quality issues are defined as "any power problem that results in failure or misoperation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment" for the purposes of this article. Regarding the container crane sector, the following power-related problems deteriorate power quality:

Power Factor, Harmonic Distortion, Voltage Sags or Dips, Voltage Swells, Voltage Transients

2.2 THE BENEFITS OF POWER QUALITY

The costs of operating a container port, the dependability of the terminal's equipment, and other customers that use the same utility service are all impacted by power quality in the terminal environment. The next paragraphs address each of these issues.

1. Economic Impact

The main motivator for operators of container terminals is the financial benefits of electricity quality. Significant economic influence may appear in a number of ways, including: Penalties Based on Power Factor.

2. Equipment Reliability

Low power quality may shorten component life and have an impact on the dependability of machinery or equipment. Power quality issues include harmonics, voltage transients, and voltage system sags and swells. These issues are interrelated. Power factor is impacted by harmonics, which are also caused by voltage transients and the same mechanisms that cause harmonic current injection in DC SCRs. Poor power factor is caused by variable speed drives, and voltage sags and swells may be caused by the same drives' dynamically shifting power factor. Specially made filters may be used to reduce the effects of harmonic distortion, harmonic currents, and line notch ringing.

3. Power System Adequacy

A power system study should be carried out before adding more cranes to an existing power distribution system in order to ascertain if the system is capable of handling the added weight of the cranes. Corrective measures for power quality may be necessary because the current power distribution systems, to which new or relocated cranes are to be linked, are inadequate. Put differently, adding equipment for power quality might make an existing power system feasible.

4. Environment

There may be no topic as significant as how electricity quality affects our surroundings. Lower demands and a decrease in system losses translate into less natural resource usage and less emissions from power plants. As inhabitants of this planet, it is our duty to promote resource conservation and back policies that clean up the air.

3.INVERTERS

3.1 Inverter:

An electrical device called an inverter changes direct current (DC) to alternating current (AC); with the right transformers, switching, and control circuits, the converted AC may be at any desired voltage and frequency.Static inverters are utilized in many different applications, ranging from big electric utility high-voltage direct current applications that transfer bulk power to tiny computer switching power supplies. Static inverters are characterized by their lack of moving components. When supplying AC power from DC sources, such solar panels or batteries, inverters are often used.An electronic oscillator with high power is what the electrical inverter is. The reason for the term "inverted" is because the first mechanical AC to DC converters were designed to operate in reverse, or "inverted," in order to convert DC to AC.An inverter works in the opposite way as a rectifier.

4.SYSTEM DESIGN

4.1 PROPOSED CONTROL METHODOLOGY:

Distribution systems often feature non-linear loads such as RL, RC, and DBR loads, which causes harmonics to develop in the source current. This study suggests an appropriate control approach, which is presented, to get the best performance. When connected to a nonlinear load, the source current (Isabc) in Figure 1 often displays specific harmonics. The PCC is injected with opposing current harmonics by the use of a shunt active filter (SAPF), and the power circuit of the SAPF is a modified seven-level boost ANPC inverter. This inverter has a strong boosting ability and minimizes both the amount of switches and switching losses.

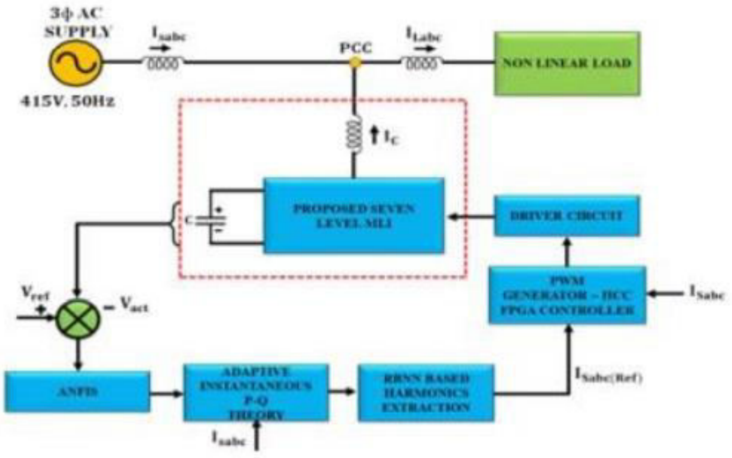

Fig 4.1: Proposed control methodology

4.2 MODELING OF THE PROPOSED CONTROL METHODOLOGY A. A PROPOSED SEVEN LEVEL ACTIVE NEUTRAL POINT CLAMPED INVERTER TOPOLOGY

A change is made to the seven-level boost active neutral point clamped (7LBANPC) inverter to improve its capability and balance its self-voltage. This involves connecting a T-type neutral point clamped inverter and connecting a capacitor in a cross-coupled arrangement. Because fewer switching devices are needed and switching losses are kept to a minimum, it is very efficient. This design, which is an ANPC inverter topology, is shown in Figure 2 and has a voltagegain that is 1.5 times larger than the source voltage.

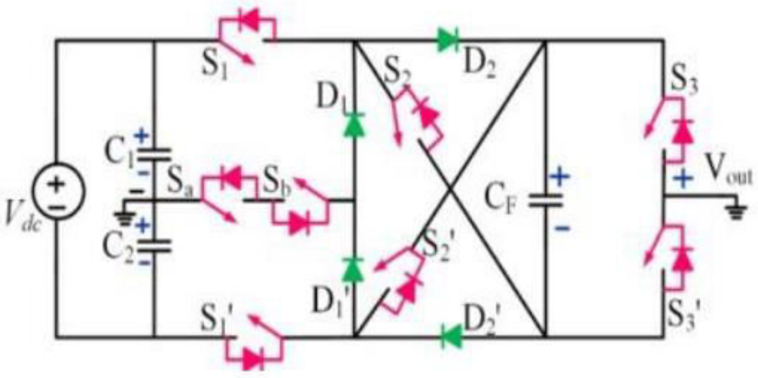

Fig 4.2: Proposed Seven-Level ANPC Circuit Diagram

Table I Switching Sequence Seven- Level ANPC Topology

V_{out}	S_1	S_2	S_3	S_1’	S_2’	S_3’	S_aS_b	Diodes	Status of CF
0	0	0	1	0	1	0	1	D_1&D_1’	-
	0	1	0	0	0	1	1	-	-
$+V_{dc}/2$	1	0	1	1	0	0	0	D_1&D_1’	Charging
$+V_{dc}$	0	1	1	0	0	0	1	-	discharging
$+3V_{dc}/2$	1	1	1	0	0	0	0	-	discharging
$-V_{dc}/2$	1	0	0	1	0	1	0	D_1&D_1’	charging
$-V_{dc}$	0	0	0	0	1	1	1	-	discharging
$-3V_{dc}/2$	0	0	0	1	1	1	0	-	discharging

Apart from Sa and Sb, all other switches have the maximum stress voltage Vdc and the stress voltage of Sa and Sb is given by half of the input voltage. The different operating modes of the 7LB-ANPC topology have been explained below.

MODE 0 (+ZERO,-ZERO)

Figure 3 depicts the operation of mode 0. In mode 0, continuous current flows from the source to load or from load to source at unity power factor by turning ON the switches D1, S3, S2’/Sa, Sb, S2, S3’ Also, it has less ON state switches, and the flow of current starts from Sa, Sb, D1, S3 or Sa, Sb, D1’ and S3’.

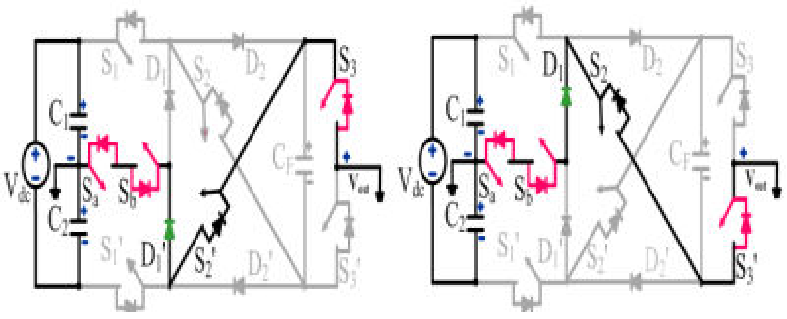

Figure 3: Mode 0 operation

MODE 1 (+Vdc/2, - Vdc/2)

Figure 4 shows the operation of mode 1. In this mode, C1 and C2 are charged and so CF is equivalent to the voltage source, therefore current flows through S1, S1', D1 and D1' which turns onS3', S3 to obtain ± Vdc/2.

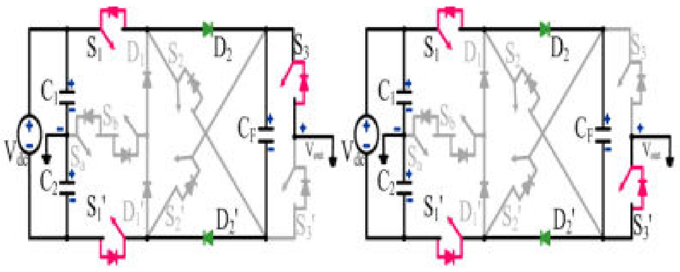

Figure 4: Mode 1 operation

MODE 2 (+Vdc, - Vdc)

Figure 5 depicts the operation of mode 2. The CF voltage +Vdc is transferred to load through Sa, Sb, S2 and S3. Here, four ON switches are taken into account. As the two terminals of CF is joined with the terminals of a diode, D2 and D2' are reverse biased.

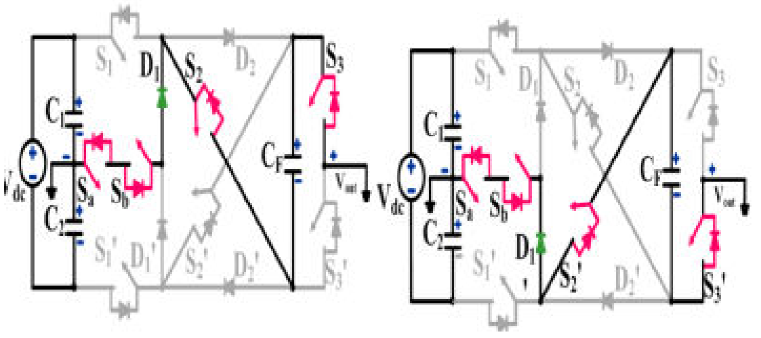

Figure 5: Mode 2 operation

MODE 3 (+3Vdc/2, - 3Vdc/2) Figure 6 depicts the operation of mode 3. By turning ON switches S1, S2 and S3, the CF voltage is summed with capacitor voltage which discharges 1.5 times voltage to load. As the two terminals of CF is joined with the terminals of a diode, D2 and D2' are reverse biased.

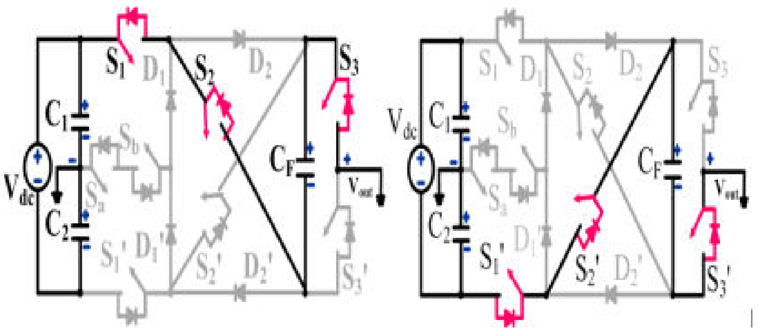

Figure 6: Mode 3 operation

In general, the output magnitudes of the existing topology are lower than the source voltage.

$$V_{omax} = 1/2dc \text{ And } V_{orms} = 1/2\sqrt{2/4}\, M\, Vdc$$

Here, V_{omax} – Peak output voltage
Vo_{rms} -- Voltage in RMS value
M - PWM modulation

The output voltage is halved to that of input naturally and so that the two capacitors maintain half the input voltage Vdc/2, also it is also self-balanced sustaining a voltage Vdc.

B. ADOPTIVE INSTANTANEOUS P-Q THEORY

This theory provides better precision and simple implementation but its drawback is that it cannot be used in unbalanced grid voltage. The computation of grid voltages to get fundamental balanced three-phase voltage components related to unbalanced voltages, a self-tuning filter is employed. To balance the issues SAPF's are modeled based mostly on P-Q Theory. In the beginning it is formed only for three-phase systems excluding neutral wire and then it is formed on behalf of three-phase four-wire system. This technique replaces three phases a-b-c into α-β and the theory is formed according to a set of rapid power already clear at a domain. So as for attaining active, reactive power components, with the aid of Clarke's transformation (α-β), the three-phase voltages namely Vsa, Vsb, Vsc and the related currents Ia, Ib, Ic are transformed. Such transformation is noted as an outcrop of three-phase components into a fixed two-axis frame and the Clarke transformation related to voltage variables and current variables are represented as,

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{sa} \\ Vsb \\ V_{sc} \end{bmatrix}$$

$$\begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \\ I_{so} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{sa} \\ Isb \\ I_{sc} \end{bmatrix}$$

The p (t) which is the instantaneous active power is represented as,

$$P(t) = V_{sa}I_{sa} + V_{sb}I_{sb} + V_{sc}I_{sc}$$

It can also be represented in a stationary frame as,

$$\begin{Bmatrix} P(t) = u_\alpha I_{s\alpha} + u_\beta I_{s\beta} \\ P_o(t) = u_o I_{so} \end{Bmatrix}$$

Here, P(t) represents the instantaneous active power, Po(t) represents the homopolar power sequence and also the representation of instantaneous reactive power is given as,

$$q(t) = 1/\sqrt{3}\left[(V_a - V_b)I_{sc} + (V_b - V_c)I_{sa} + (V_c - V_a)I_{sb} = V_\alpha I_{s\beta} - V_\beta)I_{s\alpha}\right]$$

The instantaneous reactive power q(t), defines higher than simple reactive power, and so all the voltage and current harmonics are taken into account while the habitual reactive power takes only the basics. The instantaneous active, reactive power components are represented in matrix-like,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \alpha & V_\beta \\ -V_\beta & V\alpha \end{bmatrix} \begin{bmatrix} I_{s\alpha} \\ Is\beta \end{bmatrix}$$

Every single active and reactive power has a direct and an alternating component in which the former specifies the basics of current and voltage while the latter specifies the power of harmonics related to current and voltage. To extract harmonics from the source current, the direct term is isolated from the alternating component and for this purpose, a Low pass filter (LPF) is employed. After isolation of direct term from alternating components, the harmonic components related to source currents are expressed in terms of inverse equation and is given by,

$$\begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \end{bmatrix} = 1/V_{s\alpha}^2 + V_{s\beta}^2 \begin{bmatrix} V_{s\alpha} & -V_{s\beta} \\ V_{s\beta} & Vs\alpha \end{bmatrix} \begin{bmatrix} \overline{p_s} \\ \overline{q_s} \end{bmatrix}$$

Here, represents the sign related to the alternating term and – represents the sign related to direct component of active, reactive power. Hence the reference current specifying SAPF given by,

$$\begin{bmatrix} I_{sa}^* \\ I_{sb}^* \\ I_{sc}^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \bar{I}_{s\alpha} \\ \bar{I}_{s\beta} \end{bmatrix}$$

Figure 4.3 depicts the principle of active, reactive power and this method provides a benefit that there is a preference of compensating the harmonics and reactive power. In compensation to reactive power, power is directly applied towards the reference current and so the computation block precludes the usage of any extraction filter.

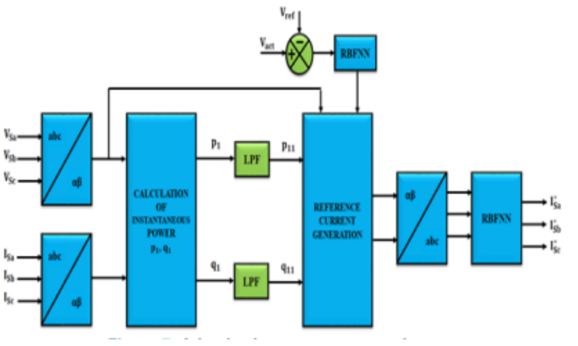

Figure 4.3: Adaptive Instantaneous p-q theory

5.SIMULATION RESULTS

5.1 SIMULATION CIRCUIT

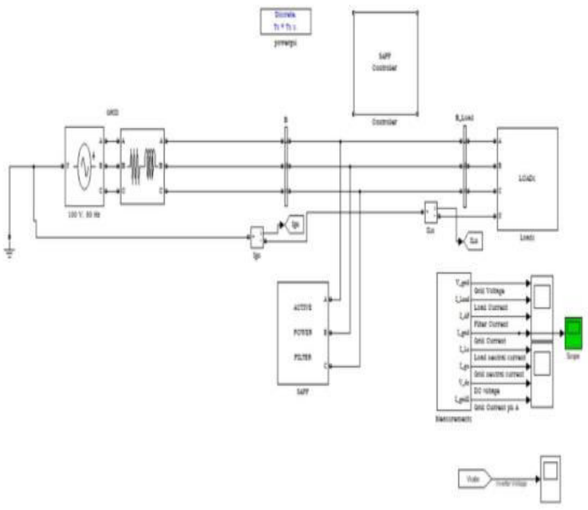

Fig 5.1: Simulink Model of Sequential Reduced Switch and PC Inverter Shunt Active Power Filter Performance Assessment Using RBFNN-Based Harmonic Current Generation

5.2 CONTROL CIRCUIT

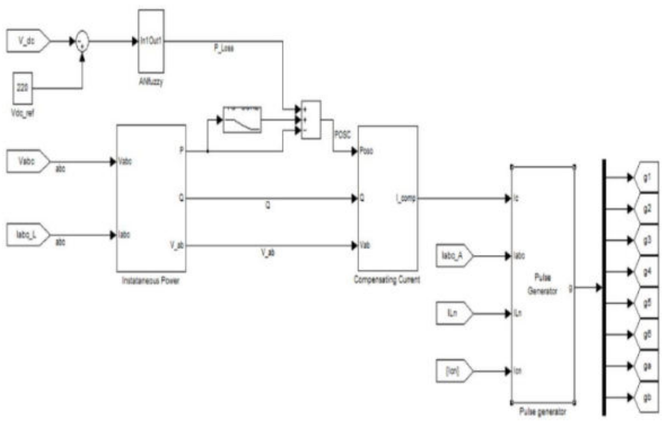

Fig 5.2: simulink model of control circuit

5.3.1 Out Put Wave Forms Of Grid Voltage,Load Current, Flied Current,Grid Current

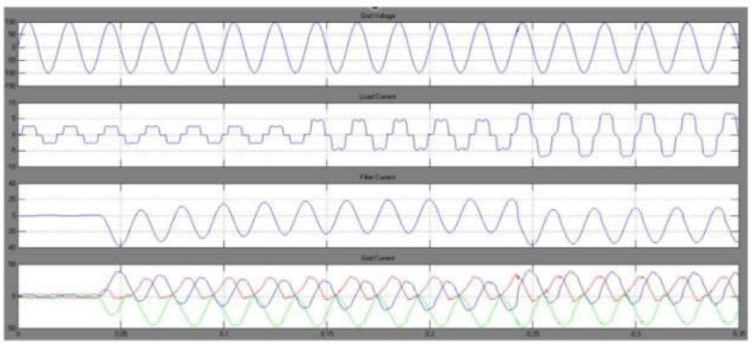

Fig 5.3.1: Out Put Wave Forms Of Grid Voltage,Load Current, Flied Current,Grid Current

5.3.2 Out Put Wave Forms Of Load Neutral Curret ,Grid Nuetral Current,Dc Current,Grid Current Ph A

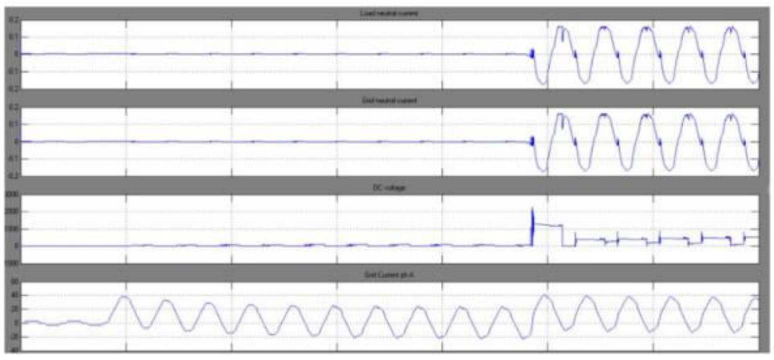

Fig5.3.2: Out Put Wave Forms Of Load Neutral Curret ,Grid Nuetral Current,Dc Current,Grid Current Ph A

5.3.3 Out Put Wave Form of Grid Current

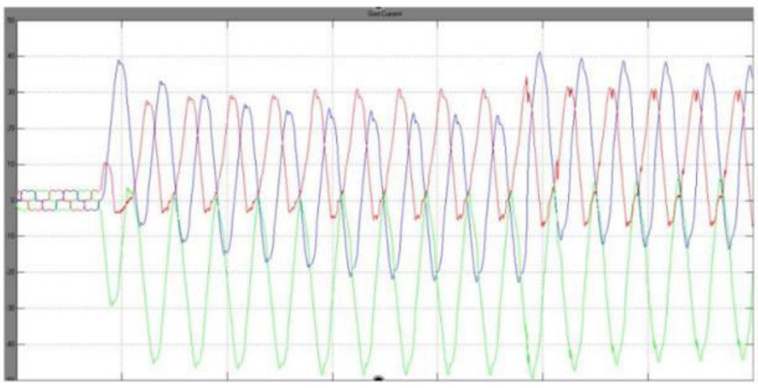

Fig 5.3.3: Out Put Wave Form of Grid Current

5.3.4 out put voltage wave form of seven level ANPC inverter

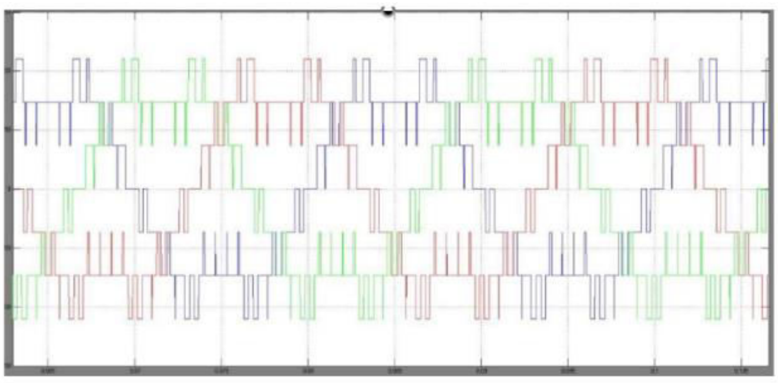

Fig 5.3.4: out put voltage wave form of seven level ANPC inverter

6.CONCLUSIONS

This study uses a modified seven-level boost ANPC inverter, which shows great boosting capabilities with a minimal amount of switches and low switching losses, to achieve reactive power compensation and harmonic mitigation. The adaptive instantaneous p-q theory with RBFNN is used to emphasize the creation of the reference current. The PI controller and Fuzzy compare the link voltage in the capacitor, which is maintained by ANFIS. The necessary gating sequence for the modified 7LB-ANPC inverter has been produced using a PWM generator with a hysteresis current controller. A thorough analysis has been done to compare the modified 7LB-ANPC with the most current approaches. The suggested technique is a good fit for harmonic mitigation, as shown by the simulation results.

7.REFERENCES

[1] This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3064715, IEEE Access Performance Evaluation of Seven Level Reduced Switch ANPC Inverter in Shunt Active Power Filter with RBFNN Based Harmonic Current Generation

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