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# Harmonics Analysis of High Power PWM Convertors Connected To Grid Using Sequential Sampling State Vector Modulation Method in SS Model

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***Abstract:*-- In this research paper, the design & development of a high power PWM convertor (12-pulse & 24-pulse convertors connected to the grid) is considered using the SVM method, which is used to reduce the harmonic contents in the supply waveforms. Simulations are performed in the Matlab-Simulink environment & the simulation results are obtained. The results shows the efficacy of the method developed for harmonic suppression.**

***Index Terms:*—Elimination, Breakers, Current, Voltage, Control, Simulation, T H D, Power semiconductor devices, Suppression, Power Quality, Harmonics, Distortion,**

## I. INTRODUCTION

Our innovative world has turned out to be profoundly reliant upon the ceaseless accessibility of electrical force/energy. Business control, i.e., power available commercially is truly empowering the today's current world to work at its bustling pace. Modern innovation has come too profoundly into our homes and professions, and with the coming of e-trade & commerce is constantly changing the way we interface with whatever is left of world. Electric vitality is a fundamental element for the modern and all-round advancement of any nation. The ideal use of this type of vitality/power can be guaranteed by a quality force/energy/power. The circumstance with power is comparative, the unwavering quality of the supply must be known and the flexibility of the procedure to varieties must be caught on immediately [1]-[10].

As a general rule, obviously, power is altogether different from some other item - it is created a long way from the purpose of utilization and is nourished to the framework together with the yield of numerous different generators and lands at the purpose of utilization through a few transformers and numerous kilometers of overhead and conceivably underground cables. Where the electrical business factories has been privatized, these system resources will be possessed, overseen and kept up by various distinctive associations or companies. Guaranteeing the nature of conveyed force/power at the purpose of utilization is no simple task undertaking and it is extremely unlikely that sub-standard power can be pulled back from the store network or rejected by the client/end-utilizer [11]-[20].

Electrical vitality/power is a key element for the modern and all-round advancement of any nation as currently without electricity, the whole world will be in dark & the country’s economy falls down drastically as every working device in the universe requires electricity. Hat’s off to thomas alva edison, benjamin franklin, who invented this great wonder, which is of great importance today. The ideal usage of this type of vitality/energy can be guaranteed by a quality electrical power with no intrusion. The circumstance with power is comparative, the unwavering quality of the supply must be known and the versatility of the procedure to varieties must be caught on [1] – [99].

Harmonic spikes have various undesirable consequences for the appropriation framework of the electrical distribution networks. 2 types are there, viz., : short

 

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& long term effects. Short impacts are generally the most recognizable and are identified with over the top over voltage mutilation. Then again, long haul (term) impacts frequently go undetected and are normally identified with expanded resistive loss or voltage stress likewise, the consonant streams created by non-straight loads can associate antagonistically with an extensive variety of influence framework gear (electrical power equipments), most strikingly capacitors, transformers, and engines, generators, bringing on extra loss, overheating, and over-burdening.

Interference with telephone cables, lines will be caused by the development of these harmonic currents. In light of the antagonistic impacts that these harmonic surges have on p q, standards have been created to characterize a sensible structure for control of harmonic surges. Its goal is to guarantee consistent state harmonic limits that are worthy considered by both electric utilities and their clients. [21]-[30].

Distortion of harmonics in power/force appropriation system can be stifled utilizing 2 methodologies in particular, latent/passive and dynamic/active fueling. The passive type of sifting/filter is the least difficult traditional answer for alleviate the mutation in harmonics. Even basically, the utilization of detached components does not generally react accurately to the progression of the electrical energy transmission frameworks. Throughout the years, these detached passive channels have created to the abnormal state of modernity. Some even tuned to sidestep or bypass the particular consonant frequencies" [31] - [40].

Harmonics are *v* and *i* frequency components which are embedded on the crest level of the normal sine *v* & *i*. The symphonious distortion in waveform issues are for the most part because of the significant increment of non-straight loads because of innovative advances, for example, the utilization of force electronic circuits and gadgets, in air conditioning/dc transmission connections, or burdens in the control of force frameworks utilizing power electronic or microchip controllers. Harmonic sources are categorized into 3 types of loads, viz., [41]-[50]:

- House-hold load
- industry load
- controlling device

Any power circulation circuit serving present day electronic gadgets will possess some level of symphonious frequencies. The surge *v* & *i* don't generally bring about issues, yet the more prominent the electrical energy or power is drawn by these advanced gadgets or other non-straight loads, the more prominent is the level of voltage mutilation. There are a number of problems which are related to the harmonic generation, they include the following [51]-[60] :

- Equipment mal-functioning.
- Sudden tripping of the breakers.
- Sudden on & off of the lights.
- Large neutral *i*.
- Conductors in the phase, loads, transformer getting heated,
- U p s suddenly getting failed,
- Transformer suddenly getting failed,
- Less power factor.
- Voltage & current surges
- Capacity of the system getting reduced [61]-[70].

How to prevent the harmonics ? The efficient method is to choose a device and have good installation practice which will definitely reduce the overall harmonic contents in the device or circuit or equipment or in a part of the network. On the off chance that the issues can't be illuminated by these basic measures, there are 2 fundamental decisions, viz., to fortify the dissemination framework to withstand *v* or *i* surges or to introduce the gadget to constrict or evacuate the harmonics. Procedures for lessening *v* or *i* surges, from shabby to more costly, incorporate latent symphonious channels, confinement transformers, consonant moderating transformers, the harmonic suppression network (hsn) and dynamic channel filtering mechanisms [71]-[80].

The harmonic effect in the system's *v* or *i* is always decided in terms of the t h d, factor, high & low level harmonic contents. In general, any industry application ask for the load v & i be free of harmonics or at the most < 5 % of harmonics. Majority of the literatures after going through them shows that a number of methodologies have been found out to lessen the t h d [81]-[90]

There are assortments of building arrangements accessible to dispose of or diminish the impact of supply quality issues and it is exceptionally dynamic zone of advancement and improvement. In that capacity, clients should know about scope of arrangements accessible and the relative merits and expenses. A portion of the vital techniques to minimize sounds/surges in *v* & *i*'s are [91]-[99]

- Filter which is passive in nature,
- filter which is active nature,
- separation transformer,
- surge reducing transformer,
- Surge suppression system, etc…

The flow of the research work is developed one after another as shown below. A background introduction W.R.T. The work done in this paper was presented in the introductory section in sec. 1. Introductory review of the current & previous work done is presented in section 2. Algorithm used is presented in section 3. Performance analysis is presented in section 4. SVM module system is presented in section 5. Development of the state space model using the SVM method is presented in section 6. Description about the converter design & development of the simulink model is presented in section 7. Simulation parameters selection is presented in section 8. Observation of the simulation results is presented in section 9. Comments on the results is presented in section 10. Comments on the FFT analysis is presented in section 11. Performance analysis of the designed converter for the reduction by varying for the different values of firing angles is presented in section 12. Conclusions are presented in section 13.this is followed by a number of references used in the development of this paper and the author biographies.

## II. INTRODUCTORY REVIEW OF THE CURRENT & PREVIOUS WORK DONE

Controlled rectifiers are considered as the most important hardware part in the field of HVDC systems in transmission lines and can be used for a number of power electronics based system operation, control and quality applications. In this section, a brief design of a 12-pulse & 24-pulse convertors connected to the grid is presented along with the harmonic analysis with its comparison statistics and thus providing a justification for the suitable ones. Mathematical equations along with analysis are also presented in this context with the development of the state space model and its inclusion in the developed simulink model.

The performance of 12 and 24-pulse convertors are herewith compared for their effectiveness both quantitatively as well as qualitatively. Some basic topological explanation of the controlled rectifiers and simulation results done using the Matlab tool are also presented in this section in order to justify the output voltage harmonic analysis. An overview of the basic topological aspects of the harmonic analysis is also presented. The simulation results along with the quantitative results show the effect of the algorithm developed for the cancelation higher order harmonics such that the power quality is also improved with the overall improvement in the power quality.

### *Algorithm used*

An algorithm called a sequential sampling SVM for the harmonic analysis is used here for the harmonic elimination and the improvement of the power quality, which is based on the Fast Fourier series.

### *Performance analysis*

The performance of the designed convertor is seen by varying the triggering angles over a wide range, say for α = 0°, 30°, 60°, 90°, 120°, 150°, 180°.

### *SVM module system*

The SVM module system to be modeled is shown in the figure below which consists of a 6-pulse convertor (full thyristorized bridge) connected to a 3ϕ-grid through a inductive load. SVM method is used for switching on and off the thyristorized bridges as it gives better performance compared to the other methods of switching's.

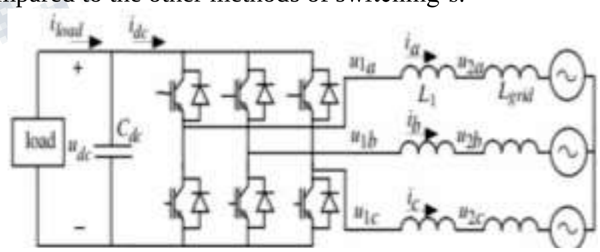


***Fig. 1 : A 6-Pulse Convertor Connected to a 3ϕ Grid, Circuit Diagram Showing a Multilevel Convertor Connected to a Power Source***

## III. DEVELOPMENT OF THE STATE SPACE MODEL USING THE SVM METHOD

Here, we develop the SS model of the system, which is used for the controller design. The inductance $L_{grid}$ is assumed to be zero and the *q*-axis of the *dq*-frame is synchronized to the vector set up by the voltages $u_{2a}$, $u_{2b}$ and

 

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$u_{2c}$. If a significant inductance is present, then the angle of the *dq*-frame changes rapidly at steps in the line currents and the inductance *L* grid should be included in the analytical models because of the rapidly changing angles of the *dq*-frame models [1]-[5]. Nominal machine parameters, i.e., the specifications of a standard system are used.

The mathematical model shown here is not only used for the theoretical analysis, but also these equations are used in the simulink block diagram for the purpose of understanding purposes and using this mathematical model, we are developing our own proposed simulink model for the purpose of harmonic elimination. Parks transformation is used here for the purpose of derivation and hence, only fundamental frequencies are used.

Any convertor consists of 4 sides, viz., the AC side, DC side, grid side and the load side. The AC side of the convertor system is modeled by differential equations for each of the 3 phases, viz., for the phase *a*, *b* and the phase *c*. We assume that the inductors are not saturated. The iron losses and copper losses due to the skin effect areneglected. The equations for the *L*-filter can be obtained as shown for a particular operating point as

$$L_1 \frac{di_a}{dt} + R_1 i_a = u_{1a} - u_{2a}$$
$$L_1 \frac{di_b}{dt} + R_1 i_b = u_{1b} - u_{2b}$$
$$L_1 \frac{di_c}{dt} + R_1 i_c = u_{1c} - u_{2c}$$

By using vector notation, these above 3 equations can be written in the $\alpha\beta$ – frame as

$$L_1 \frac{d\underline{i}^{\alpha\beta}}{dt} + R_1 \underline{i}^{\alpha\beta} = \underline{u}_1^{\alpha\beta} - \underline{u}_2^{\alpha\beta}$$

and in the *d-q* frame as

$$L_1 \frac{d\underline{i}^{dq}}{dt} + \left(R_1 + j\,\omega_g L_1\right)\underline{i}^{dq} = \underline{u}_1^{dq} - \underline{u}_2^{dq}$$

The equations are having all the resonance modes, i.e., it is a mixture of all the harmonic levels starting from the 1st level to the *n*th level. As we need selective harmonic reduction (only first few harmonics), we have to decouple this mathematical equation. These mathematical governing equations are finally decoupled using park's transformation so that the final equation represents the equations of only few harmonic modes. The decoupled equation is finally converted in the state space form as a generalized mathematical model representing a first order linear differential equation given by

$$\dot{x}_L(t) = \frac{d\mathbf{x}_L}{dt} = \mathbf{A}_L \mathbf{x}_L + \mathbf{B}_L \mathbf{u}_L$$

where

**x**(**dot**) is the derivation of the state, *t* is the time,
**A** is the system matrix,
**B** is the input matrix,
**u** is the input vector
**x** is the state vector & is given

$$\mathbf{x}_L = \begin{bmatrix} i_d & i_q \end{bmatrix}^T = \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

Where the states of the system are taken as the direct axis current and the quadrature axis currents Here, we have used the state space theory for developing the mathematical model. The input vector **u** is given by

$$\mathbf{u}_L = \begin{bmatrix} u_{1d} & u_{1q} & u_{2d} & u_{2q} \end{bmatrix}^T = \begin{bmatrix} u_{1d} \\ u_{1q} \\ u_{2d} \\ u_{2q} \end{bmatrix}$$

The system matrix **A** is given by

$$\mathbf{A}_L = \begin{bmatrix} -\frac{R_1}{L_1} & \omega_g \\ -\omega_g & -\frac{R_1}{L_1} \end{bmatrix}$$

Similarly, the input matrix **B** is given by

$$\mathbf{B}_L = \begin{bmatrix} \frac{1}{L_1} & 0 & -\frac{1}{L_1} & 0 \\ 0 & \frac{1}{L_1} & 0 & -\frac{1}{L_1} \end{bmatrix}$$

The state space equation for the AC side of the convertor side system is linear zed about an operating point. Finally, the linear state space equation for the *L*-filter and is finally given in the standard state space model given by

$$\dot{\mathbf{x}}_L = \mathbf{A}_L \mathbf{x}_L + \mathbf{B}_L \mathbf{u}_L$$
$$y_L = \mathbf{C}_L \mathbf{x}_L + \mathbf{D}_L \mathbf{u}_L$$

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Where, $y$ is the output, **C** is the output matrix, **D** is the transmission matrix, which is taken as zero as we are using only one circuit model. If we had used another level, then we would have got the transmission matrix. The load is connected to the converter, which is purely on the DC level. The current drawn by the load side is given by the equation

$$\mathbf{C}_{dc}\frac{du_{dc}}{dt} = i_{load} - i_{dc} = i_{Load}\text{, i.e., } i = \mathbf{C}\frac{dq}{dt}$$

Here, in this equation, $i_{Load}$ is the current flowing by the capacitor $\mathbf{C}_{dc}$. In general, the overall state space model of the convertor system can be obtained by substituting all the above equations in the state model given by

$$\dot{\mathbf{x}}_L(t) = \begin{bmatrix} -\frac{R_1}{L_1} & \omega_g \\ -\omega_g & -\frac{R_1}{L_1} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} sw_d & 0 \\ 0 & sw_q \end{bmatrix} \begin{bmatrix} \frac{1}{L_1} & 0 & -\frac{1}{L_1} & 0 \\ 0 & \frac{1}{L_1} & 0 & -\frac{1}{L_1} \end{bmatrix} \begin{bmatrix} u_{1d} \\ u_{1q} \\ u_{2d} \\ u_{2q} \end{bmatrix}$$

$$y(t) = \begin{bmatrix} sw_d & 0 \\ 0 & sw_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_{1d} \\ u_{1q} \\ u_{2d} \\ u_{2q} \end{bmatrix}$$

Where, the first equation is called as the state equation, while the second equation is called as the output equation. It has to be noted that the states are taken as the direct axis current and the quadrature axis currents.

The current in the DC side can be found from the AC side power following the power on the DC side should be equivalent to the power on the ac side of the convertor. In the entire design, the losses are assumed to be neglected. The prompt power on the AC side and the DC side of the convertor can be derived as follows…

$$p_{ac} = \mathrm{Re}\left\{ \underline{u}_1^{\alpha\beta}\, \underline{i}_1^{\alpha\beta} \right\}$$

and

$$p_{dc} = u_{dc}\, i_{dc}$$

The voltage vector of the convertor sideis best given by a switching function as

$$i_{dc} = \mathrm{Re}\left\{ sw^{\alpha\beta}\, \underline{i}_1^{\alpha\beta} \right\}$$

which is equal to

$$i_{dc} = sw_\alpha i_\alpha + sw_\beta i_\beta$$

where $sw_\alpha$ and $sw_\beta$ are the $\alpha$ and $\beta$-components of the switching vector $sw_{\alpha\beta}$. The DC current can also be written in $dq$-coordinate form as

$$i_{dc} = sw_d i_d + sw_q i_q$$

As a result, a complete state space equation in the $dq$-coordinates for the VSC connected to the grid by the $L$-filter is finally given by using the $i_{dc}$ equation in the load current equation as

$$\mathbf{C}_{dc}\frac{du_{dc}}{dt} = i_{load} - sw_d i_d - sw_q i_q$$

Thus, finally, the mathematical model is presented with $L$-filter. This is going to be used in our simulink model developed in the Matlab-Simulink environment, which is used for the simulation purpose and for the removal of the harmonic contents and to improve the THD.

## IV. DESCRIPTION ABOUT THE CONVERTER DESIGN & DEVELOPMENT OF THE SIMULINK MODEL

In the work considered, pulse convertors are used at 2 levels, viz., 12 and 24-level for converting the DC voltage in the power system to AC voltage and vice-versa. In the circuit diagram, 6 thyristorized switches are used in the 12-pulse level and for a 24-pulse level, it is a parallel combination. In the thyristorized bridge, each switch will be turned on at each 30° phase delay. This switching is done in order to avoid the short circuit between the switches in the rectifier circuit. An amount of ($\alpha$°) is given to the convertor to increase or decrease the output voltage / current. It is to be noted that the entire thyristorized bridge is clubbed as a sub-system, viz., converter-1 to 4 respectively. Two 6-pulse convertors are used in 12-pulse design, where as four 6-pulse convertors are used in 24-pulse design with a delay phase angle of 15° in between each pulse level.

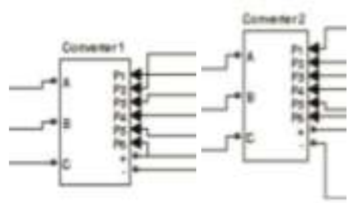

***Fig. 2 : Converter developed as a sub-system in the Simulink environment***

In the 2 simulink models developed (one for a 12-pulse & other for a 24-pulse), we have used the state vector modulation (SVM) method inside the blocks and all the equations shown above are converted into block-sets in the simulink diagram and shown as sub-systems. The controller

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model is developed in Simulink and the basic functions such as the step signals, comparators, integrators, multiplexers and the control loops, thyristorized bridges, scopes, sinks, state space models, connectors, etc… are being used in the model development with the control algorithm being put in the loop inside the matrix. All these blocks are available in the simulink library, which has to be pulled one by one into the *new.mdl* file, model to be built and with the correct simulation parameters inside the block.

The numerical values of the state space mathematical model (A, B, C, D) which are obtained are also put in the block, which is pulled from the simulink library. All these numerical values of the models are incorporated in the 12-pulse and 24-pulse convertor simulink model developed in the Simulink environment for controlling the vibrations. Apart from these, various toolboxes such as control system tool box, sim-power-systems tool box, signal processing tool boxes available in the simulink library is being used. Scopes are connected at the o/p & i/p's to observe the different waveforms. Load is also connected at the output side of the model.

## V. SIMULATION PARAMETERS SELECTION

Various parameters are to be set in the different blocks that are used in the development of the simulink model before running the developed Simulink model, which are shown in the below figures respectively. Once the block is being selected, it is being double clicked & the simulation parameters are entered into it and saved.

***Observation of the simulation results***

The developed Simulink model is run with relevant simulation parameters for a particular value of simulation time & the waveforms are observed. Once, the whole system is designed and developed in the simulink environment, the simulation is run for a certain period of time. All the waveforms are observed on the individual scopes connected to the output points of the system. Note that the developed controller, when put in feedback loop with the convertor system (closed loop control system), showed the simulation results when the simulink model is run.

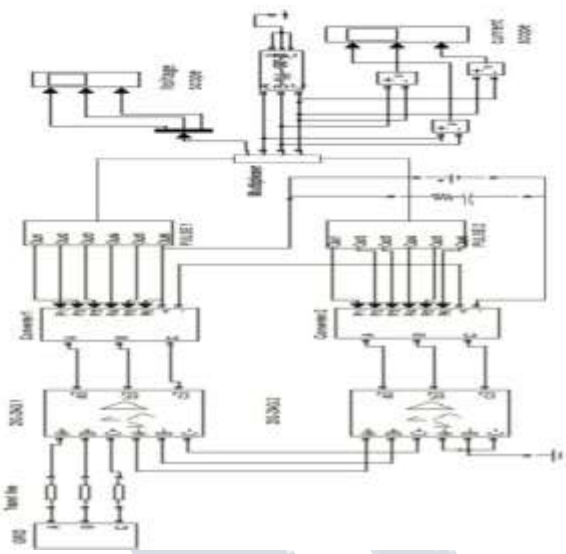

***Fig. 3 : A 12-Pulse Convertor Simulink Model for Reducing Harmonics using State Vector***

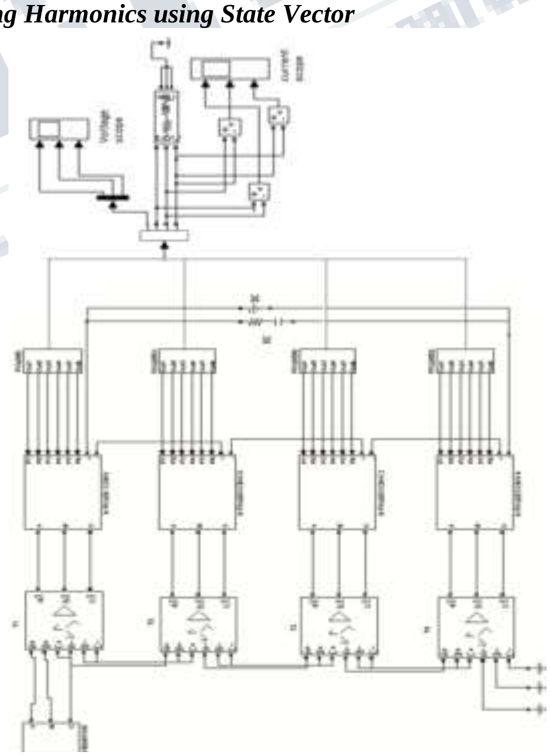

***Fig. 4: A 24-Pulse Convertor Simulink Model for Reducing Harmonics Using State Vector***

 

In this context, the responses are observed with & without the controller. Plot of the states are shown in the sim results. From the results, it can be observed that the o/p states reach the final steady state quickly in no time and the harmonic contents are reduced substantially. Simulink model is run and the various responses with and w/o the controller are observed. Each graph has time (in secs) along the *x*-axis and *y*-axis is the amplitude of the convertor output voltage (volts) or current (amps). Simulations were done for a particular time period and that too for a particular load (2 kW).

*One of the special features in this section is the usage of six 2-level convertors, whereas in the other sections, a direct 12-pulse convertor was used along with the state space model of the convertor system.*

To accomplish great execution, instantaneous f/b procedure is considered for the 12 and 24 pulse convertors. To begin with, the convertor display in *abc*-casing is presented, including the successive testing module and the channel framework.

Second, the model is changed over to *dq*-outline for the accommodation of the plan of the controller. After all these procedures, the control model is then obtained. In the wake of utilizing the decoupling control, the control show (state space model) is disentangled and the controller parameters can be upgraded for element execution and framework adjustment.

Proper filtering leads to lowest harmonic distortion, i.e., purifying the electric signal for the grid. Power electronic converters used in majority of the applications are a well-known source of harmonic distortion, which can cause all types of negative effects, such as overheating, equipment failure, motor losses and network tripping. Therefore, harmonic current emissions are becoming an increasing area of interest for power system operators and those responsible for defining international standards.

Harmonic filters are used after the power converter and the results are seen to be quite effective, the only problem is the smoothness of the waveforms is not, which is due to presence of the noise factor, but anyhow the output is smoothened after the incorporation of the filter on the grid side.

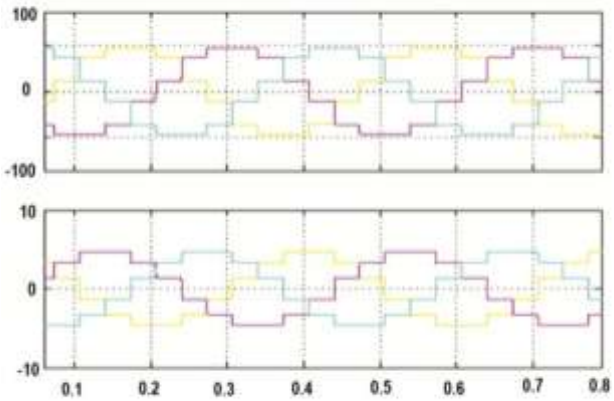


***Fig. 5 : A 12-pulse convertor's o/p v and i before the harmonic removal by the filter***

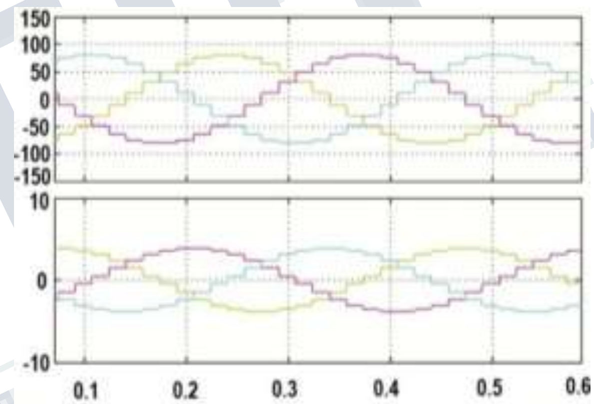


***Fig. 6 : 24-pulse convertor's o/p v and i before the harmonic removal by the filter***

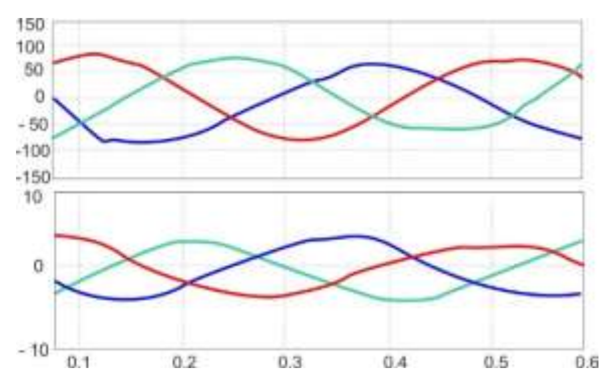


***Fig. 7 : 12-Pulse convertor's o/p v and i after the harmonic removal by the filter***

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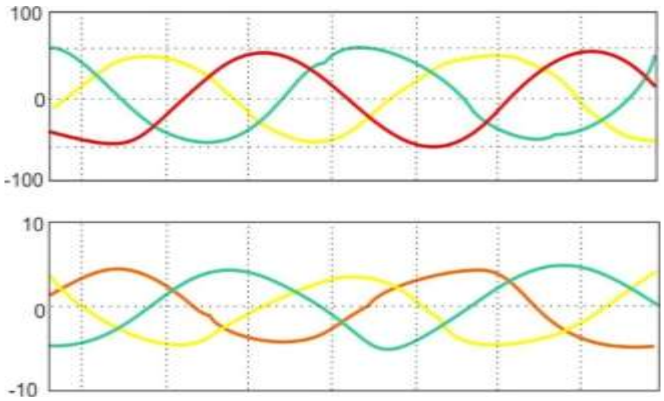


*Fig. 8 : 24-Pulse convertor's o/p v and i after the harmonic removal by the filter*

## VI. COMMENTS ON THE THD RESULTS

The quantitative results of the 2 type of convertors for THD and the current ripple are shown in the table for a 2 KW load. From these quantitative results, it is inferred that the THD, current ripple is the lowest for a 24-pulse convertor. This is because of the fact that with the incorporation of higher pulse convertors, there will be more effect will be there with respect to the THD as a result of which the % of the current ripples goes on decreasing and the power output quality increases. It can be further observed that more the number of bridge circuits / switches, the percentage error comes down, but the complexity in the circuit increases, the cost increases with a question on its reliability and its successful operation with less controllability and poor regulation.

| Convertors | Load side voltage | Load side current | *v* THD in % | Current *i* ripple (%) |
|---|---|---|---|---|
| 12-pulse | 107.8 | 8.55 | 43.32 | 39.17 |
| 24-pulse | 117.8 | 7.27 | 35.17 | 29.6 |

*Table 1 : Harmonics content levels with a load of 2 kw before incorporation of filtering effect*

| Convertors | Load side voltage | Load side current | *v* THD in % | Current *i* ripple (%) |
|---|---|---|---|---|
| 12-pulse | 107.8 | 8.55 | 4.22 | 3.71 |
| 24-pulse | 117.8 | 7.27 | 2.12 | 2.6 |

*Table 2 : Harmonics content levels with a load of 2 kw after the incorporation of filtering effect*

| Type of harmonic elimination method | 3-ϕ, 4-level inverter |
|---|---|
| THD Before Harmonic Suppression (load v) | 0.4332<br>43.32 % |
| THD After Harmonic Suppression (load *v*) | 0.0422<br>4.22 % |
| THD Before Harmonic Suppression (load *i*) | 0.3917<br>39.17 % |
| THD After Harmonic Suppression (load *i*) | 0.0371<br>3.71 % |
| Power Factor | 0.94 |

*Table 3 : Comparison of different parameters w.r.t SVM PWM state space based model designed circuit*

Also, the total harmonic distortion for the output waveforms was calculated using the THD formulas for the current and voltage and the results were tabulated neatly in the form of a THD reduction table given above. From these quantitative results, it can be inferred that using SVM scheme, the technique has worked successfully as before the introduction of the harmonic filter, the THD was 0.3917and after the introduction of the filter, the THD was 0.0371, i.e., there is a substantial reduction in the harmonic contents of the load current. Similarly, the THD was 0.4332 before the introduction of the filter and after the introduction of the filter, the THD was 0.0422, i.e., there is a substantial reduction in the harmonic contents of the load voltage. This can be seen from the Matlab output THD waveform results. The net power factor was improved to 0.94.

## VII. COMMENTS ON THE FFT ANALYSIS

Harmonic spectrum of the convertor and grid side voltage and current was presented in the simulation results. The FFT analysis was also carried out both on the convertor side as well as on the grid side after which the fundamental

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frequencies and the harmonics were observed and the simulation results were observed. Here, for the sake of convenience, only the parameters at the load side are shown. It can be observed from this table that the convertor side and the grid side voltage remain constant, whereas there is a decrease in the THD % value. It has to be noted in this context that while seeing the FFT spectrum, a normalized modulation index is taken into account in both the cases of the level inverters.

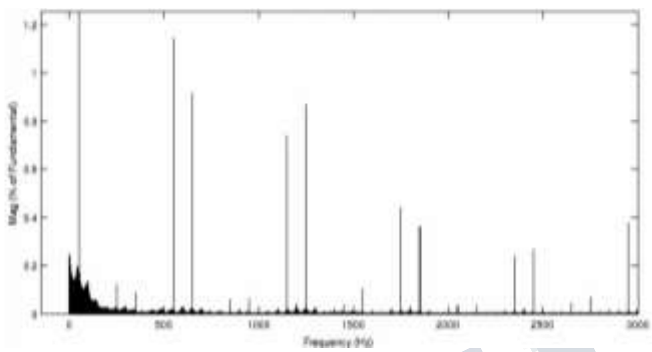

*Fig. 9 : Harmonic spectrum on load side of the 12-pulse converter*

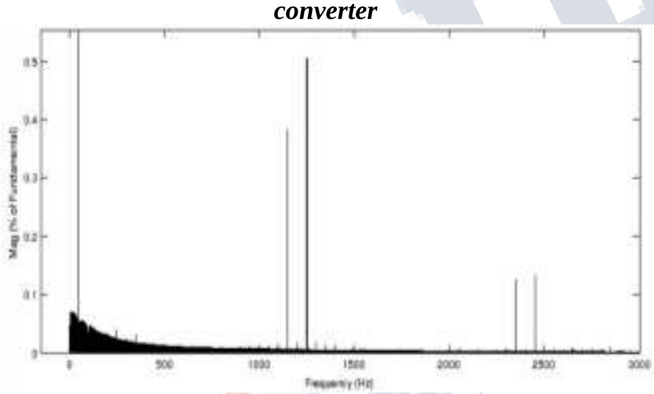

*Fig. 10 : Harmonic spectrum of load side for a 24-pulse converter*

The harmonics analysis seen in the spectrum consists of the fundamental component and some other components, i.e., the spikes in the spectral FFT analysis for different pulse convertors, which is due to the noise that occurs during the harmonic removal process. The main advantage of this type of design is the short circuit current reduction. If the higher-frequency ripples are controlled, we can say that we can mitigate harmonics still further.

***Performance analysis of the designed converter for THD reduction by varying for the different values of firing angles***

The table shown below gives a overview of how the THD is reduced for different values of the firing angles of α, ranging from 0° to 180° [87].

| | α = 0° | α = 30° | α = 60° | α = 90° | α = 120° | α = 150° | α = 180° | Overall |
|---|---|---|---|---|---|---|---|---|
| 12-pulse | 4.10 | 4.02 | 3.69 | 3.59 | 3.19 | 2.39 | 1.98 | 4.2 |
| 24-pulse | 1.38 | 1.34 | 1.28 | 1.24 | 1.22 | 1.19 | 1.10 | 2.6 |

*Table 4 : Harmonics content levels with a load of 2 KW after filtering effect for different firing angles*

Here, the simulink models of VSC/s for 2 levels, viz., 12 and 24 pulse level were considered for performance analysis by varying the values of firing angles from 0 to 180°. It was found that 24-pulse VSC was better compared to the previous one and the comparison on THD shown in the table, further proves that the 24-pulse convertor connected towards the load side gives better response towards as the harmonics are highly reduced compared to other convertors without any harmonic level filters.

The performance of 12 and 24 pulse level convertor strategies were considered in terms of convertor, loadand grid voltage and current THD along with their fundamental components are studied and compared for their best performance. Also, the THD was obtained for various values of firing angles. The simulation results for different strategies with their harmonic spectrums are also presented. In all these cases, symmetry and synchronization, is maintained. This is essential for high power low switching frequency applications.

The triggering angle variation is also considered with α = 0°, 30°, 60° and it is inferred that as once the triggering is varied, the THD goes on reducing, from which it could also be assumed that the harmonics are being eliminated. Since the THD and other indices are reduced or canceled the power quality of the convertors are also enhanced.

## VIII. CONCLUSIONS

Research was done w.r.t. Analysis of the surge-harmonic effects on the system components & its effectiveness was studied in greater depth resulting in a number of contributions towards the same during the switching on/off of the device process. The early location, concealment of sounds in electrical, electronic, pc, instrumentation, mech. And aviation framework systems are an essential parameter which must be considered w.r.t. The wellbeing, unwavering quality, effective operation of a wide range of system frameworks which are working on power and must be handled genuinely & intelligently. Extensive literature survey was being carried out in this exciting field.

Finally, the design & development of a high power PWM convertor (*12-pulse & 24-pulse convertors connected to the grid*) was done using the SVM method and was successfully demonstrated by Matlab-Simulink environments and hence the simulation results show the effectiveness of the method adopted for harmonic suppression / reduction / elimination, which could be justified from the quantitative results and from the observed waveforms.

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