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Simulation of a 3-ϕ, 2-Level Inverter with a Discrete 3-ϕ PWM Generator to Reduce the Harmonics and Improve the Power Quality

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Abstract

In this paper, the design & development of a simulink model for the harmonic elimination using a simulation of a 3-ϕ, 2-level inverter with a discrete 3-ϕ PWM generator to reduce the harmonics and improve the power quality is presented. 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.

Keywords : *Elimination, Breakers, Current, Voltage, Control, Simulation, T H D, Power semiconductor devices, Suppression, Power Quality, Harmonics, Distortion, 3-ϕ, 2-Level Inverter, Discrete 3-ϕ PWM Generator*

1. 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 & 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. Review about the 3-ϕ, 2-level inverter with a discrete 3-ϕ PWM Generator is presented in section 2, which is followed by the operating principle along with the model design in section 3. Section 4 gives the model specifications and the development of the Simulink model for harmonic elimination in Matlab environment is presented in section 5. The section 6 depicts the observation of the simulation results, followed by the FFT analysis in section 7 & the comments on THD in section 8. The sec. 9 concludes the work. This is followed by a number of references used in the development of this paper and the author biographies.

2. Introductory review

In this research paper, 3-ϕ, 2-level inverter with a discrete 3-ϕ PWM generator is presented, the aim of which is to reduce the harmonics in the power supply and improve the power quality. At the end, the harmonic analyses of the various waveforms are also carried out along with their THD informations, which can be seen from the simulated results. In this context, a 3-ϕ, 2-level inverter is modeled by using a novel method and with the usage of suitable switching control strategies with the help of PWM concept to carry out harmonic elimination / suppression.

3. Operating principle along with the model design

The 3-ϕ, 2-level inverter is very much capable of improving the AC power in spite of load fluctuations, switching sequences and is the one of the important power electronic system for suppressing the harmonics distortion in an electrical system.

The operating principle of each level being designed could be summarized as follows ………...

A 6-step SCR bridge is used for 3-ϕ inverter by using 6 switches, 2 switches for each phase. It has to be noted here that each step is being defined as a change in the time operation for each of the transistors to the next transistor, well defined in the proper sequence. For one cycle of 360°, each step would be of 60° interval for a 6-step inverter.

In this circuit, very large capacitors are connected at the input terminals (as a capacitor bank) to make the DC input constant and also to suppress the harmonics that are being fed back to the source. There are 2 patterns of gating the transistors in the bridge unit. In one of the type of patterns, each transistor conducts for a period of 180° and in other pattern, each transistor conducts for another 120° so that for both the patterns' gating signals are applied and removed at a interval of 60°of the output voltage waveform. Both the levels require a 6-step bridge inverter.

The power electronics harmonic system thus developed uses a pair of 3-ϕ, 2-level pulse width modulated voltage source converters. This pair is connected back to back like a darlington pair (emitter follower 2 transistors connected in back to back configuration). An AC inductive load is connected to the pair of inverters. A 3-ϕ transformer is also acting as the isolation in between the output source and the input source along with the transformer couplings. The main function of the induction of the pair of transformers is to reduce the harmonic filtering.

The concept of leakage inductance of the transformer is used. SCR Bridge (pair of two connected in parallel as shown in the Simulink model) is used in the inverter configuration with a combination of full bridge fashion. Snubber circuits are used for protection purposes also along with free-wheeling diodes. Controlling of the inverter is done in closed loop configuration. PWM generator or modulator is used to generate the pulses for 3-ϕ, 2-level, converters using twin configuration, which is operated in the synchronous mode. In this mode, the carrier signal is synchronized with a phase locked loop (PLL) as a result of which the carrier chopping frequency is determined solely on the switching ratio of the output of the generator.

An AC source is used in conjunction with the harmonic reduction transformers, which is used to modulate the carrier signals. We have chosen the bus voltage at a level of 300 V DC, which will be +ve/–ve 150. As per the norms, the chopping frequency selected should be 18 times the frequency of the AC supply, i.e., $18 \times 50 =$ 900 Hz.

4. Model details

Specs : The rating of the system is chosen as 0.5 kW, 1 kVAR, 50 Hz, 300 V_{rms}.

Bus voltage : at a level of 300 V DC +ve/–ve 150 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.

5. Development of the Simulink model

The simulink model is constructed using library blocks such as thyristors bridges, diodes, transformer couplings, DC sources, PWM units, DC sources, gain blocks, FWDs, transformers, inductive loads, scopes, sinks, output sources, comparators, pulse generators and the connectors. All these mentioned blocks are available in the simulink modelling library and are interconnected as per the design process for harmonic reduction.

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. Convertors are used for harmonic reduction purposes. A inductive load of 0.5 kW, 1 KVAR is used at the output stage. Scopes are connected at various points to observe the voltage & current waveforms along with display boxes for seeing the numerical values of the voltages & the currents. The necessary simulation parameters are set inside the relevant boxes and devices in the said environment.

Note that when the DPWM converter is off, harmonic contents are present in the waveforms. When the DPWM

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converter shown in the Simulink diagram is ON, the harmonic contents are reduced & we get a smoothened waveform.

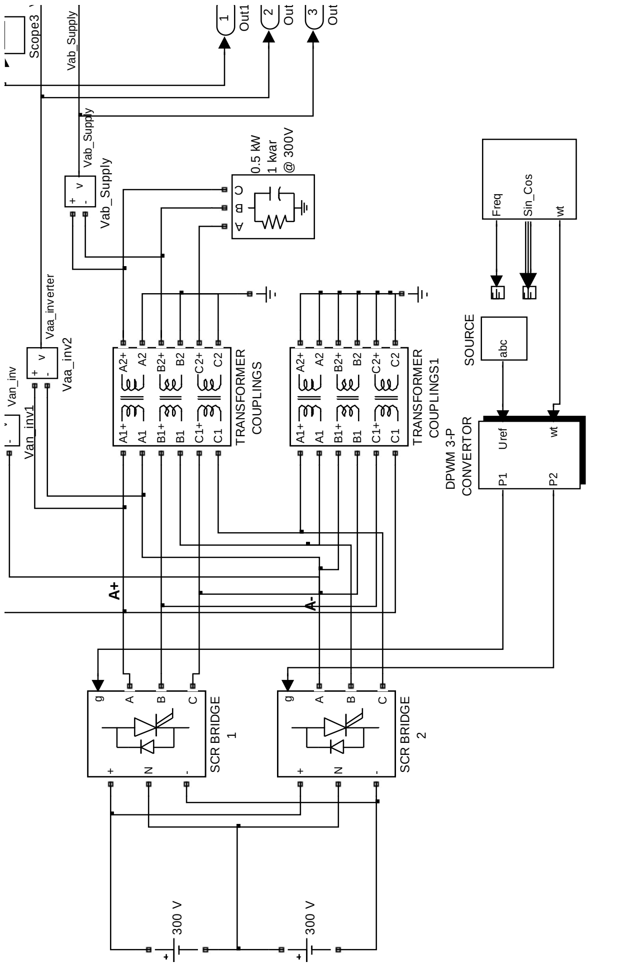

Fig. 1 : Schematic circuit using simulink model for the 3-phase 2-level inverter for harmonic reduction to improve PQ

The execution of the 3-stage 2-level 6 switches inverter (SCR bridge 1 & 2) had been developed and enhanced by utilizing pulse-width-modulation (PWM) control plan. The utilization of a 2-level inverter diminishes the symphonious parts of the o/p voltage contrasted and the customary 3-stage inverter at the same exchanging recurrence. Since 2-level SCR bridges are used, only 2 transformer couplings are used for isolation purposes.

Out ports 1, 2, 3,… can be used to take the data to the Matlab workspace for plotting the waveforms. It needs no extra reactors or transformers to diminish the symphonious parts. At that point, it is suitable for medium voltage and medium power frameworks. The outlined and executed 2-level inverter understood the necessities, and R-C load by the required estimations of voltage and recurrence.

6. 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 3 individual scopes connected to the output points of the system. The 3 output signals observed are

- the phase to neutral voltage generated by the inverter,
- a phase voltage of the inverter which is generated by the parallel combination and
- the voltage of the load in phase to phase fashion.

The set values in the design could be seen in the output waveforms, i.e., ± 300 V. FFT analysis is done in order to display the frequency spectrum of the output waveforms. The 1st harmonics occur around the multiples of the doubled carrier frequency (as per norms) and can be seen from the simulation results that the total harmonic deduction is upto the level of 22.24 %, which is of very high standards in the harmonic suppression.

Further, after the incorporation of the controller, it can be seen that the out waveform is highly sinusoidal, except at the beginning of the cycle, where there will be a transient due to switching of the thyristors, but finally settle and improves the power quality of the output waveform (3rd figure).

Fig. 2 : Output of voltage waveform before and after the incorporation of the 3-phase 2-level inverter (of one phase), the second figure shows the distorted wave before the incorporation.

The load, which has been connected to the output of the level inverter shows that harmonics are absent from both the line-line and line-neutral voltages and consequently absent from the currents. Since the system has good balanced currents in the other 2 phases B and C (note that this current can be obtained by adding 120°and 240° phase shift w.r.t. the current of phase A and hence for the sake of convenience, only one phase waveforms are shown in the simulation result. The simulation has to run for a quite amount of time in order to obtain a steady state waveform which shows the suppression of the harmonic contents and thus improving the power quality.

7. FFT Analysis

The FFT analysis was performed on the voltage & current waveforms in the Simulink environment. From the FFT analysis, we can see the %age of the THD reduction. It can also be seen from the FFT analysis that the total harmonic deduction is very good and substantially reduced. From the FFT analysis, we see the reduction in the THD percentage.

8. Comments on the reduction of THD

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 the selective harmonic elimination scheme, i.e., eliminating a particular harmonics, the technique has worked successfully as before the introduction of the harmonic filter, the THD was 0.5234and after the introduction of the filter, the THD was 0.0655, i.e., there is a substantial reduction in the harmonic contents of the load current.

Table 1 : Comparison of Different Parameters wrt 3-Phase 2-Level Inverter

Type of harmonic elimination method	3-ϕ, 2-level inverter
THD Before Harmonic Suppression (load v)	0.7204 72.04 %
THD After Harmonic Suppression (load *v*)	0.2224 22.24 %
THD Before Harmonic Suppression (load *i*)	0.5234 52.34 %
THD After Harmonic Suppression (load *i*)	0.0655 6.55 %
Power Factor	0.85

Similarly, the THD was 0.7204 before the introduction of the filter and after the introduction of the filter, the THD was 0.2224, 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 0.85 as shown in the table below.

9. 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 is 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.

In this context, 3-ϕ 2-level inverter arrangements were exclusively demonstrated by Matlab-Simulink environments and hence the results show the effectiveness of the method adopted. The simulation results show the effectiveness of the method proposed.

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