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Reduction of harmonic component in voltage sourced circuits using IGBT's and diode's using PWM technique

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***Abstract:* -- In this paper, the reduction of harmonic component in voltage sourced circuits using IGBT's and diode's using PWM technique 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 in the power electronics based systems.**

***Keywords*—Elimination, Breakers, Current, Voltage, Control, Simulation, T H D, Power semiconductor devices, Suppression, Power Quality, Harmonics, Distortion, PWM, IGBT.**

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 & 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

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Vol 2, Issue 11, November 2016

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. Simulation parameters selection is presented in section 4. Running of the developed Simulink models, observation of the results is presented in section 5. 1-□ , half bridge inverter with 1 pair (with Simulink diagram & results) is presented in section 6. 1-□ , full bridge inverter with 2 pair (with Simulink diagram & results) is presented in section 7. 1-□ , full bridge inverter with 3 pair (with Simulink diagram & results) is presented in section 8. Comparision of the FFT for all the 3-stages is done in sec. 9. Comments on the reduction of THD in the work considered is presented in section 10. Conclusions is presented in section 11.

II. INTRODUCTORY REVIEW OF MULTI-STAGE INVERTERS

In this research paper, single phase circuits, i.e., inverters can be designed in such a way that maximum harmonic contents can be reduced using single stage, double stage, triple stage half bridge-full bridge inverters so that the harmonic contents are reduced when the load switching on & off takes place.

IGBT's & diode blocks are used in the construction of the multi-stage models. IGBT's are very powerful switching devices which can be used for full harmonic suppression and obtain a smoothened output free of harmonics. After designing a proper filter and putting at the output of the inverter, the harmonics free waveforms can be observed. Finally, FFT analysis also can be made in this regard using the FFT commands and the 'powergui' tools available in the Matlab-Simulink window.

The design is done in 3 stages, viz.,

1. stage 1 (one pair of IGBTs),
2. stage 2 (two pair of IGBTs) and
3. stage 3 (three pair of IGBTs).

IGBT and Diodes are used to design the voltage source converter, which are controlled in the OL fashion using the discrete PWM generator. In this context, it is to be noted that the IGBT is a modified version of a gate turn off switch (GTO) or a Metal Oxide Silicon Field Effect Transistor (MOSFET). In these devices, the forward voltages of the models are not considered as they don't have any role to play. The harmonic elimination system consists of three 1-□ models,

- one is a half bridge (single stage),
- another is a full bridge (double stage) and
- the third is a full bridge (triple stage) and all the 3 are compared to see the best performance.

III. DEVELOPMENT OF THE SIMULINK MODEL

The simulink model is constructed using thyristors bridges, DC sources, transformers, inductive loads, gain blocks, multiplexers, FWDs, scopes, sinks, output sources, comparators, pulse generators and the connectors. All these mentioned blocks are available in the simulink modelling library. All these mentioned blocks are available in the simulink modelling library, once the circuit is designed, all the blocks have to be pulled from the simulink library into the model and has to be built, the file being named as *.mdl. 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. Note that each leg of an inverter consists of a pair of IGBT's.

In our design, 3 designs are used in parallel combination as it a well-known fact that harmonic filters when connected in parallel will yield excellent harmonic reduction in the output voltage.

In the Simulink model shown, the 3 circuits uses the same DC voltage (Vdc = 100V), carrier frequency (1 KHz) and modulation index (m = 0.9), this has been selected to make a comparison showing the effecting of parallelism and cascading of the stages. Various parameters are to be set in the different blocks that are used in the development of the simulink model. Scopes are connected at relevant points to see the voltage & current waveforms.

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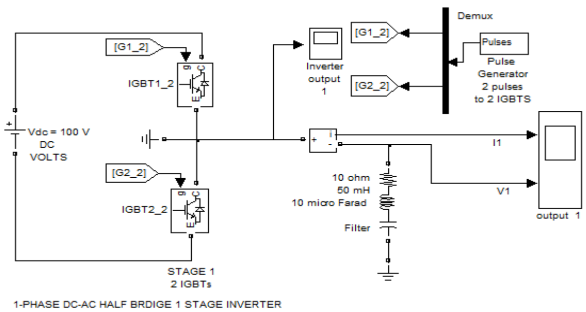

Fig 1 : Simulink models for the 1-stage harmonic reduction systems

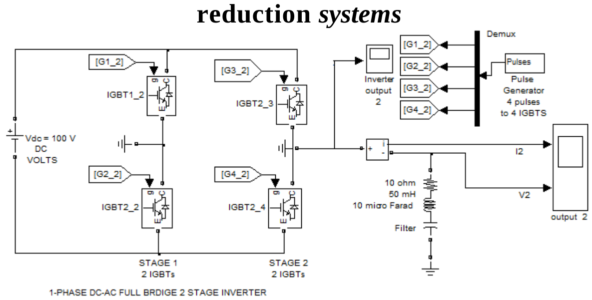

Fig 2 : Simulink models for the 2-stage harmonic reduction systems

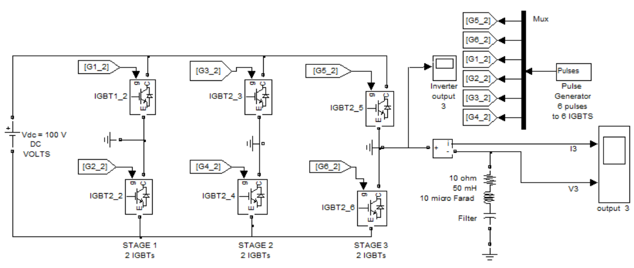

Fig 3 : Simulink models for the 3-stage harmonic reduction systems

The output signals can be seen in 3 different scopes connected to each of the stages, which shows that there is a drastic improvement in the harmonic level suppression in the 3^{rd} stage.

A RLC filter stage is designed in such a way that it anti harmonic signals are produced for the suppression of the harmonic devices which are produced due to the inverter actions and to obtain smooth output waveforms, further to improve the power quality. Outputs are observed for RL, LC, R, L type filters also @ the output of the load.

The modelling design is done in 3 stages, viz.,

- 1-ϕ, half bridge inverter with 1 pair
- 1-ϕ, full bridge inverter with 2 pair
- 1-ϕ, full bridge inverter with 3 pair

IV. 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.

Running of the developed Simulink models, observation of the results

The 3 simulink models as shown above are run for the requisite simulation time, 2 waveforms are observed, one at the output of the inverter, which is affected with harmonic content and the other at the output of the filter combined with the load, which is harmonic free. From the simulation results, it can be seen that the difference between before and after the incorporation of the harmonic filter, how the harmonics are removed to a greater extent. This shows the effectiveness of the method demonstrated in this section as to how to improve the power quality and obtain smoothened outputs at the receiving ends. *Note that wherever switches come, next immediate o/p will be the harmonics.* Hence, to eliminate this, we can use the multi-stage leg inverters.

1-ϕ, half bridge inverter with 1 pair (with Simulink diagram & results)

In a 1-ϕ, half bridge inverter, it consists of only a pair of IGBTs in series, to which the inputs are given from the PWM generators (supplying pulses) and the V_{dc} voltage. In turn, the output of the 1-ϕ half bridge is connected to a RLC filter bank, which suppresses the harmonic contents in the output supply voltage, which can be seen from the scope 1. Since there are 2 IGBTs in series in a line, the outputof the pulse generator is multiplexed and given to 2 devices.

Once, the model is developed, the simulation is run for a specific amount of time, which can be specified in the simulation time parameter section. The FFT analysis or the frequency spectrum can be demonstrated once the simulation is completed for the specific set simulation period. In the 1^{st} case, for the 1-ϕ, single stage half-bridge inverter generates a bipolar voltage (–100V or

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Vol 2, Issue 11, November 2016

+100V) and the harmonics occurs around the carrier frequency of f_c = 1 KHz with a maximum of 90 % at f_c.

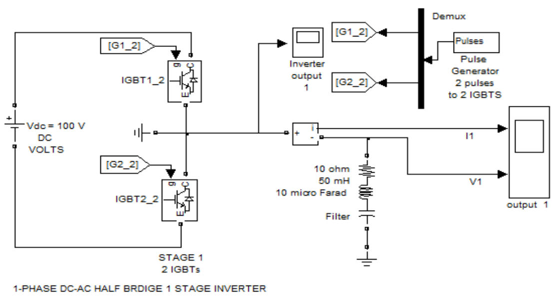

Fig. 4 : Simulink model of a 1-ϕ, half bridge, 1-stage inverter to remove harmonics

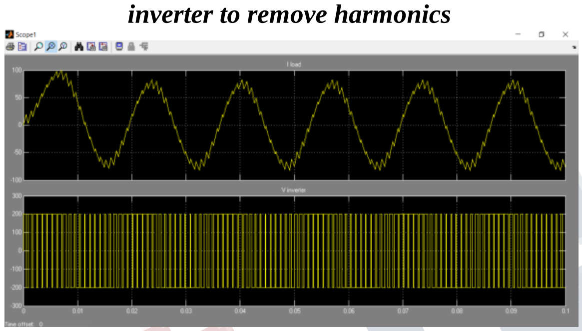

Fig. 5 : Simulink output display of harmonic components waveform of the inverter stage-1.

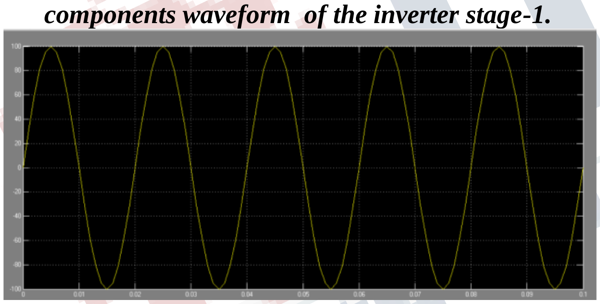

Fig. 6 : Simulink output display of harmonic components waveform of the inverter of stage-1, after filtered o/p

1-ϕ, full bridge inverter with 2 pair (with Simulink diagram & results)

In a 1-ϕ, full bridge, it consists of 2 parallel pairs of IGBTs in series, to which the inputs are given from the PWM generators (supplying pulses) and the V_{dc} voltage. In turn, the output of the 1-ϕ full bridge is connected to a RLC filter bank, which suppresses the harmonic contents in the output supply voltage, which can be seen from the scope 2. Since there are 2 IGBTs in series in a line, the output of the pulse generator is multiplexed and given to 4 devices (2 pairs in parallel).

For the 2nd case, the 1-ϕ, double stage full-bridge inverter generates a mono-polar voltage varying from +200 V to –200 V, alternating between the half cycles. In this context, it can be observed that for the same index of modulation, the fundamental component is twice the value of V_{dc} compared to the single stage half bridge.

Harmonics generated by the 1-ϕ, 2-stage full-bridge are lower and they appear at double of the carrier frequency (maximum of 50% at 2*1 khz ± 50 Hz), as a result, the output waveform obtained with the 1-ϕ 2-stage full-bridge is smoother and has reduced from 90 % to 40 % and the harmonics occurs around the carrier frequency of 2 KHz with a maximum of 50 % at f_c.

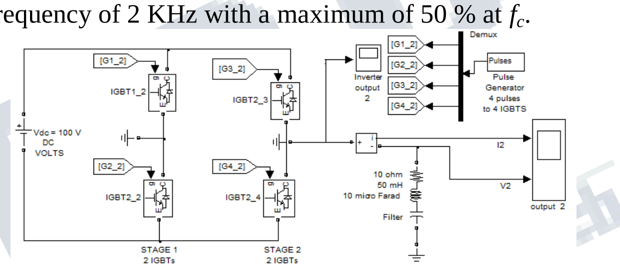

Fig. 7 : Simulink model of a 1-ϕ, full bridge, 2-stage inverter to remove harmonics

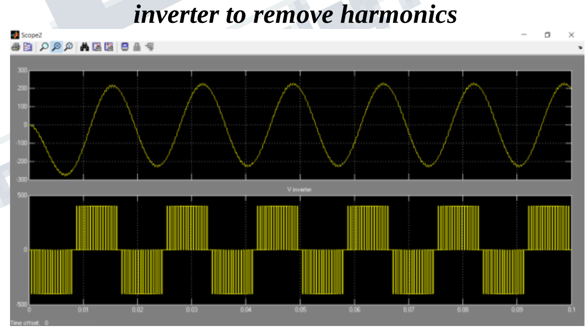

Fig. 8 : Simulink output display of Harmonic Components Waveform of the Inverter stage-2

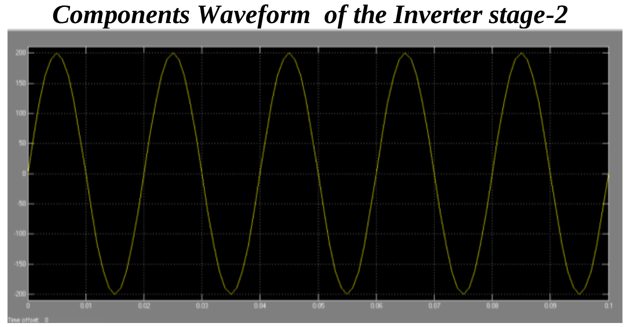

Fig. 9 : Simulink Output display of Harmonic Components Waveform of the Inverter of Stage-2, after filtered O/P

1-ϕ, full bridge inverter with 3 pair (with Simulink diagram & results)

In a 1-ϕ, full bridge inverter with 3 pairs, it consists of 3 parallel pairs of IGBTs in series, to which the inputs are given from the PWM generators (supplying pulses) and the V_{dc} voltage. In turn, the output of the 1-ϕ full bridge is connected to a RLC filter bank, which suppresses the harmonic contents in the output supply voltage, which can be seen from the scope 3. Since there are 6 IGBTs in series parallel coupled, the output of the pulse generator is multiplexed and given to 6 devices (3 pairs in parallel).

Similarly, for the 3rd case, the 1-ϕ, 3-stage full-bridge inverter generates a mono-polar voltage varying from +300 V to –300 V, alternating between the half cycles. In this context, it can be observed that for the same index of modulation, the fundamental component is thrice the value of V_{dc} compared to the single stage half bridge. Harmonics generated by the 1-ϕ 3-stage full-bridge are still lower and they appear at triple the carrier frequency (maximum of 10 % at 3*1 KHz ± 50 Hz), as a result, the output waveform obtained with the 1-ϕ 3-stage full-bridge is smoother and has reduced to 5 % and the harmonics occurs around the carrier frequency of 3 KHz with a maximum of 5 % at f_c.

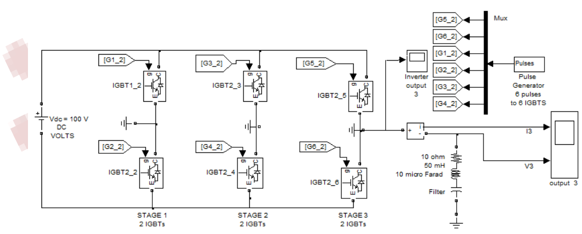

Fig. 10 : Simulink model of a 1-ϕ, full bridge, 3-stage inverter to remove harmonics

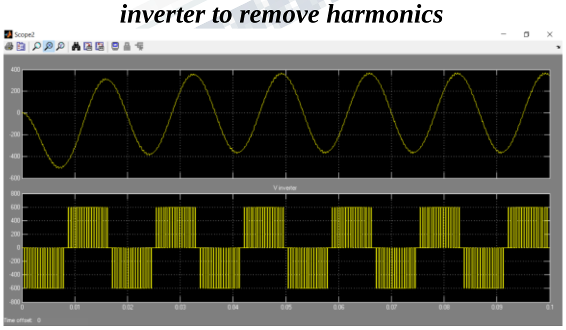

Fig. 11 : Simulink output display of harmonic components waveform of the inverter stage-3

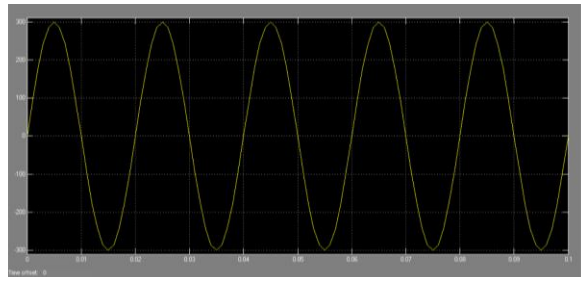

Fig. 12 : Simulink o/p display of harmonic components waveform of inverter of stage-3, after filtered o/p

Comparision of the FFT for all the 3-stages

If you now perform a FFT on the 1st stage load output waveform, it can be noticed that the THD of load current is 10 % for the half-bridge inverter, 5 % for the 1-ϕ 2-stage full-bridge inverter and only 2 % for the 1-ϕ 3-stage full-bridge inverter. Hence, it can be concluded for the best performance that the 1-ϕ 3-stage full-bridge inverter is the best for harmonic suppression, but at the same time, the cost, complexity of the system increases.

Comments on the reduction of THD in the work considered

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 below. From these quantitative results, it can be inferred that using a PWM scheme, has worked successfully ; as before the introduction of the harmonic filter, the THD was 0.2961 and after the introduction of the harmonic filter, the THD was 0.0265, i.e., there is a substantial reduction in the harmonic contents of the load current. Similarly, the THD was 0.3517 before the introduction of the filter and after the introduction of the filter, the THD was 0.0272, 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 0.88.

Table 1 : Comparison of different parameters w.r.t IGBT designed circuit for the 3rd case

Type of harmonic elimination method	3-ϕ, 4-level inverter
THD Before Harmonic Suppression (load v)	0.3517 35.17 %
THD After Harmonic Suppression (load *v*)	0.0272 2.72 %
THD Before Harmonic Suppression (load *i*)	0.2961 29.61 %
THD After Harmonic Suppression (load *i*)	0.0265 2.65 %
Power Factor	0.88

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, 1-ϕ 3-stage inverter arrangements were exclusively demonstrated by Matlab-Simulink environments and hence the results show the effectiveness of the method adopted for harmonic suppression, which could be justified from the quantitative results and from the observed waveforms. Hence, it can be concluded for the best performance that the 1-ϕ 3-stage or 3-leg full-bridge inverter is the best for harmonic suppression, but at the same time, the cost, complexity of the system increases.

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