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A New Solution to Improve Power Quality of Renewable Energy Sources Smart Grid by Considering Carbon Foot Printing as a New Element

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Abstract: *This particular article reveals a prototyped interface current control protocol which is ideal for multilevel converters and it's utilization with a three-phase cascaded H-bridge inverter. This kind of administration approach utilizes a discrete-time type of the device to estimate the longer term benefit from the current for many voltage vectors, as well as decides on the vector which in turn decreases an expense purpose. A result of the multitude of voltage vectors obtainable in a multilevel inverter, numerous computations are expected, producing challenging execution with this strategy in a typical control program. A new improved strategic approach with the demonstration using physical framework as well as Matlab system significantly decreases the number of computations without influencing the actual system's effectiveness is suggested. Experimental outcomes intended for five-level inverters confirm the suggested strategy. Additionally, author considered the socio-environmental effects occurring due to carbon foot printing as per KYOTO protocol and demonstrates the implementation of prototype carbon foot printing control sub-protocol for minimization of carbon foot printing occurring due to microbial fuel cell micro-grid setup. Hence this will help to manage attitudinal goals to improve electricity resource quality and efficiency.*
Keywords: *CFP, H-bridge, MLI, RES, smart grid.*

I. Introduction

Lots of efforts are active worldwide to fulfill the global responsibilities to decrease varieties of greenhouse gas emissions, several organizations assimilate ecological problems within their operations, focusing prospective consequences within their whole operational and execution strategies. A number of methods along with metrics are formulated to determine the ecological influence of a solution within the technical set up execution. Apart from this there is certainly need to enhance quality of power outcome. Therefore, to contemplate electrical power quality factor is important whilst computing micro-grid carbon foot printing matrix.

A domain which includes accumulated importance nowadays is the carbon footprint (CFP), which in turn quantifies the environment influence of greenhouse gas (GHG) emissions in a execution life cycle point of view [1]. On the other hand, much more capturing techniques can be found; probably the most notable is an appropriate Life Cycle Evaluation (LCE). Much like the CFP, a LCE concentrates on energy system, including all of the techniques associated with energy generation and distribution from the initial stage till final stage. Unlike the CFP, LCE analyzes every one of the ecological effects of the technique, besides the benefits to environment change [2]. Hence it is important to develop solution to minimize carbon foot printing while developing solution to enhance power quality. This will be very core solution for carbon foot printing to minimize CFP occurring due to implementation of various power quality improvement experiments as well as final interface implementation.

Now, focusing to core research we can note that, specific technical aspect of multilevel converter technological know-how can be a extremely productive substitute for medium-voltage (microbial fuel cell micro-gird) as well as high-power purposes (national grid) and in addition intended for different purposes wherever high power quality is essential [1], [2].

Many energy generation systems produce CO2 eventually throughout their process cycle. Probably none of such systems are completely 'carbon free', process cycle supply evaluation is utilized to evaluate the quantity of CO2 released by each and every technologies. Fossil fuelled power technology contains the major carbon footprint (up to 1,000gCO2 /kWh). Many emissions come up through system functioning, minimal carbon' systems include reduced process cycle carbon emissions (<100gCO2 /kWh). The majority of CO2 is imparted through non-operational stages, potential carbon footprints is usually decreased for many power system facilities if excessive CO2 emission levels are fuelled by minimal carbon strength resources.

The effective use of converters handles a number of features as subsequent: active filter systems [4], along with commercial purposes including fuel cell techniques, gasifier systems as well as small engine propulsion. We can find well-established topologies of such inverters: neutral connection, external capacitor, and H-bridge (HB) [5]. This particular report refers to the H-bridge topology, which often includes only one phase of H-bridge inverters in sequence reference to self-sufficient dc inbound links of equivalent voltage, to deliver the overall end result voltage towards the load [6]. The conventional approaches for management of HB inverters utilize simple control along with phase-shifting of pulse width modulation (PWM) [7]-[9] modulation as a way to produce the transitioning impulses for managing the converter. Additional modulation strategies to minimal transitioning rate of recurrence are also suggested [10]–[12].

Lately, latest approaches are analyzed with the current management of electrical power inverters. Most notable, prototype carbon footprint control (PCFC) continues to be applied for controlling the of power converters because of its numerous benefits, similar to rapid active response, simple addition of unsymmetrical responses along with limitations associated with method, and the overall flexibility to incorporate different technique prerequisites within the control strategy [13]–[15]. PCFC looks at a type of the device so as to forecast the long run conduct of the technique over the time. Micro-grid interface estimation functionality shows the specified conduct of the executable approach. PCFC is definitely an issue certainly where a routine of upcoming fluctuation is attained by reducing the interface function. The initial component of the routine is utilized, and whole computation is replicated at the time of each and every trial interval.

Because of the rapid reduction of a continuous signal to a discrete signal, time span employed in the management of converters, dealing with the computational issue of interface control on-line just isn't useful. One particular technique is to apply a specific alternative of interface control, dealing with the computational issue off-line. To ensuing controller is a lookup graph and may be applied without having major computational attempt. This specific alternative is employed for the management of a dc–dc converter [16].

Given that power converters having a variety of phases, provided by the feasible permutations with the phase of the transitioning equipment, the PCFC optimization issue could be simple and decreased towards forecast of the conduct of the method for every single feasible phase. Subsequently, each and every forecast is examined applying the interfacing function, and the phase which decreases it really is chosen [3,8]. This is the unique strategy which has been effectively tried for management of current in a three-phase inverter and a matrix converter, power management in an important front-end rectifier [3].

In multilevel converters, current control is used for a 3 level inverter [7], and an asymmetric 27-level CHB inverter [9] utilizing each of the transitioning phases of the program. Current control method for discerning harmonic removal is suggested in [3]. Nevertheless, within a symmetric H-Bridge, numerous transitioning phases along with redundancies are offered. Consequently, this becomes complicated to apply the control protocol applying typical signal processors, especially when large transitioning frequency is needed.

II. Case Study

In this paper, more efficient approach of prototype carbon footprint control (PCFC) management is proposed so that to minimize the computational efforts required for choosing the appropriate voltage vectors, by identifying a set of the attainable vectors for the prediction interface algorithm which also embed the carbon calculation matrix. However the proposed strategy can be applied for many levels, a five-level inverter is considered as a case study for prototyping of interface algorithm. Results for five-level H-Bridge inverters are demonstrated here with microbial fuel cell grid as an input. Definitely this approach help to minimize heat generation due to excellent power quality management and in-turn; carbon foot printing will be reduced.

Within the last couple of years, there has been a rise in volume of case research of carbon foot printing. Many of them considered almost all 3 tiers of existing approach to carbon foot printing calculations, however probably none of the studies defined them. Likewise, there seemed to be not any reference to boundary assortment. Table 2 provides, various carbon foot printing research for energy units. Although it is said that GHG emissions from energy equipment are remarkably very sensitive to ecological circumstances as well as administration techniques, probably none of the carbon foot printing research was depending on precise measurements. This research aims at Emissions & Generation Resource Integrated Database (eGRID) end result emission rates before usage of power quality device and also after utilization of power quality device to approximate the indirect emissions from grid delivered electricity acquisitions for greenhouse gas (GHG) inventories, carbon footprint calculators. eGRID incorporates functional information like emissions, various kinds of emission rates, generation, resource combination, as well as heat input. Emissions are claimed for 3 greenhouse gases (GHGs) – carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O); 2 standards air-borne pollutants nitrogen oxides (NOx), along with sulfur dioxide (SO2); and another harmful air pollutant, mercury (Hg). We demonstrated input grid section in figure 1(b).

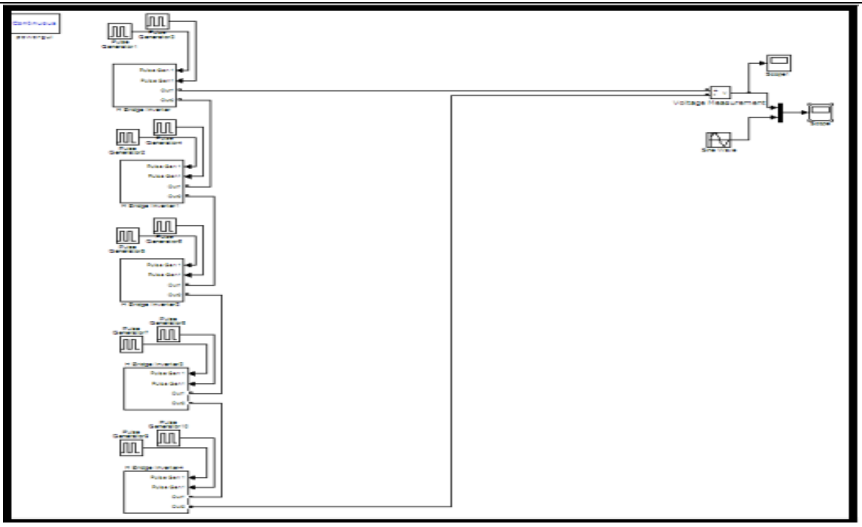

Figure 1(a): Matlab Simulation circuit representation with MFC as an input to test power quality of 5 level H-Bridge Inverter

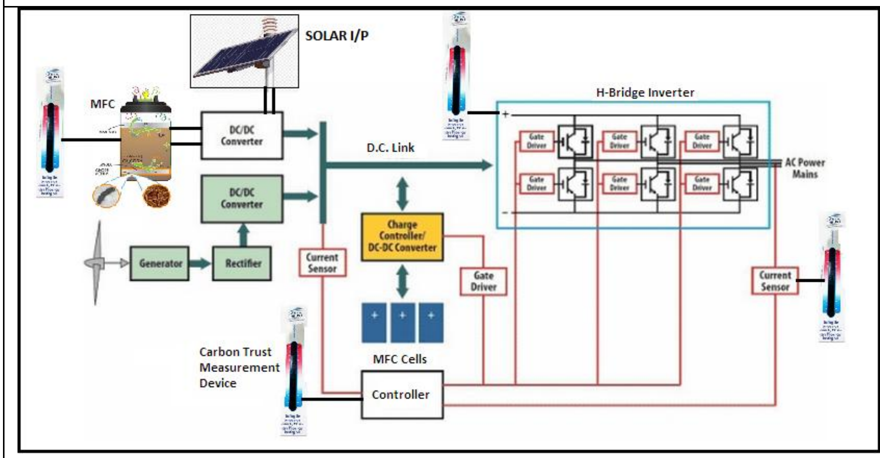

Figure 1(b) : Generalized representation of Renewable energy sources / eGRID input power quality testing and carbon foot printing analysis for H-Bridge Inverter

III. Implementation Of H-Bridge Inverter For Renewable Energy Sources

Figure 1(a) shows the simulation diagram which is parallel to hardware implementation of multilevel three-phase inverter with microbial fuel cell (MFC) as an input as representation shown in figure 1(b). MFC will generate power which we need to convert and use at the output / load side. The task is to manage the good power quality with minimization of carbon foot printing which often ignored when we think for energy generation plant.

Focusing over topology, it includes a three-phase 5-levels H-Bridge inverter along with a pair of MFC in every cycle. Every MFC is provided with a three-phase diode connection rectifier using a dc-link voltage V_{DC}. Every MFC can certainly produce an end result voltage $-V_{DC}$, 0, and V_{DC}. For every phase, the amount of low voltage ranges will be

$L = 2MFC + 1$ …………………………………….. (1)

Where number of levels will be $p = 5$ and $'MFC'$ is the number of series connected microbial fuel cells in one limb. In intended inverter, the voltage level combinations K_n is

$K_p = p^3$ ……………………………………….… (2)

Alternatively, each and every microbial fuel cell offers a pair of transitioning impulses and with MFC cells with every limb, the particular voltage for the limb with the inverter regarding binary transitioning impulses will be

$V_{aP} = V_{DC} \sum_{i=0}^{MFC} (Q_{ia,1} - Q_{ia,2})$ …………….…….. (3)

TABLE 1-Phase H-Bridge Inverter Voltage Vectors with 'MFC' Microbial Fuel Cells

Units of Microbial Fuel Cell	Voltage level	Approximate Number of Step Response (actual test) considering experimental accuracy 95%	Approximate Number of Step Response (Matlab test) considering simulation accuracy 100%
1	5	19	20
2	5	61	100
3	5	127	120
MFC	5	$12MFC^2 + 6MFC + 1$	

Where $Q_{ia,1}$ and $Q_{ia,2}$ are transitioning impulses with the microbial fuel cell i and branch $'a'$. This feasible transitioning architecture K_q for H-Bridge inverter with MFC cells in every branch is

$K_q = 2^{6MFC}$ ……………………………………… (4)

For instance, within H-Bridge inverter having 2 microbial fuel cells in every connection, there's an overall of 990 achievable changing phases, which is a quite large numbers of phases intended for applying to discover the optimum alternative. Because every cycle can certainly produce 5 voltage levels, an overall total of 20 step responses in simulation (19 in actual test) are achievable in a three-phase inverter. Through most of these 20 step responses, a number of are usually obsolete (hence in actual test as per Table-1 are 19), leading to 100 various step responses as per Matlab simulation (and 127 as per actual test). The complete amount of step responses in actual test and Matlab simulation for distinct amounts of microbial fuel cell for each cycle is detailed in Table I. Based on Figure. 1(a, b), the differential formula with the current of one connection (a) for three-phase RL load available with the inverter is depicted as:

$L\frac{di_q}{dt} + Ri_q = V_{q0}$ ………………………………… (5)

where V_{q0} is the voltage through the load with respect to neutral position. Nevertheless, the voltage through the load with regard to the inverter voltage will be

$V_{q0} = V_{qN} + V_{P0}$ ………………………………….. (6)

Where V_{P0} is defined as,

$V_{P0} = v_{mfcm} = \frac{V_{qN} + V_{sN} + V_{mfcN}}{3}$ ………………………….. (7)

The type of load is depicted furthermore utilizing the subsequent vector alteration:

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = \begin{bmatrix}2/3 & -1/3 & -1/3\\ 0 & \sqrt{3}/3 & -\sqrt{3}/3\end{bmatrix}\begin{bmatrix}a\\ b\\ c\end{bmatrix} \quad \text{…….. (8)}$$

Where 'q', 's', and 'mfc' are the three-phase elements of power components, and α and β are the vector elements. Applying this transformation, (5) can be re-computed as a vector representation as

$L\frac{di_{\alpha,\beta}}{dt} + Ri_{\alpha,\beta} = V_{\alpha,\beta}$ ……………………..…………………….(9)

Where $V_{\alpha,\beta}$ becomes the voltage step response of H-Bridge inverter and $i_{\alpha,\beta}$ becomes the load side current response.

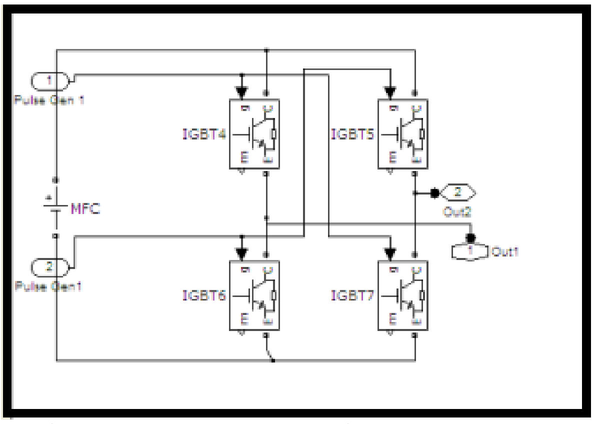

Fig. 2 Interface control with microbial fuel cell smart Pico-grid input.

IV. Renewable Energy Source Interface Approach

The key concept of the interface current processing for micro-grid (MFC grid) employed in this specific paper is to forecast the conduct of the load current for every achievable voltage vector produced through the inverter. The forecast of the current is dependent on the type of the device. Also, this forecast can be utilize to predict carbon foot printing elements like, heat dissipation and gasifyer emission etc. This is very important as, if current element is not controlled properly; there is a possibility of rise in heat dissipation.

Hence we get,

$$\frac{di_{\alpha,\beta}}{dt} \approx \frac{i_{\alpha,\beta}[k+1]-i_{\alpha,\beta}[k]}{T_s} \qquad \text{.................................... (10)}$$

Using eq. (9), the subsequent term is acquired for the forecasted interface current vector:

$$i[k+1]_{\alpha,\beta} = \frac{T_s}{L}\left(V_{\alpha,\beta}[k] - i_{\alpha,\beta}[k]\left(R - \frac{L}{T_s}\right)\right) \qquad \text{…..……….... (11)}$$

This specific formula is going to be utilized in the interface controller to forecast the long run readings with the interface current for the provided voltage vector.

V. Carbon Footprint Analysis- An Ignored Element Of Power Quality Enhancement

All power generation systems produce carbon dioxide (CO2) along with varieties of greenhouse gas emissions. To evaluate the effects of technological know-how precisely, the complete CO2 portions released within a system's existence need to be determined. Emissions are usually both immediate arising in the course of functioning of the energy plant, and indirect developing through some other non-operational stages of the life cycle. Fossil fuelled systems hold the greatest carbon foot prints, since they burn off these kinds of fuels throughout functioning. Non-fossil fuel structured systems including wind, solar, hydro, nuclear etc, are also known as 'low carbon' or 'carbon neutral' mainly because they don't emit CO2 throughout their functioning. On the other hand, they may be not 'carbon free' kinds of generation because CO2 emissions do come up in different stages of their life cycle for instance through transmission, distribution losses, decommissioning or power quality maintaining devices and their switching.

Now-a-days, microbial fuel cell (MFC) grid and solar energy for rural energy generation is an efficient solution for waste to energy approach. But, MFC releases negligible CO2 during process and power system devices used for maintaining power quality release more CO2 as per our study. Hence there is need of carbon prediction matrix (CPM) to make smart (micro) grid as a "carbon neutral" system. This CPM can be clubbed together with power quality matrix to predict the quality of power with minimum carbon foot printing. As shown in figure 1(b), we utilized carbon trust's thermometer to find out carbon foot printing during our experiment. To compare carbon foot printing with other power system devices, we again used carbon trust thermometer for one year to test various switches and transformers. As an outcome of this analysis, we noted readings for one year. Next section of this paper will focus over these readings.

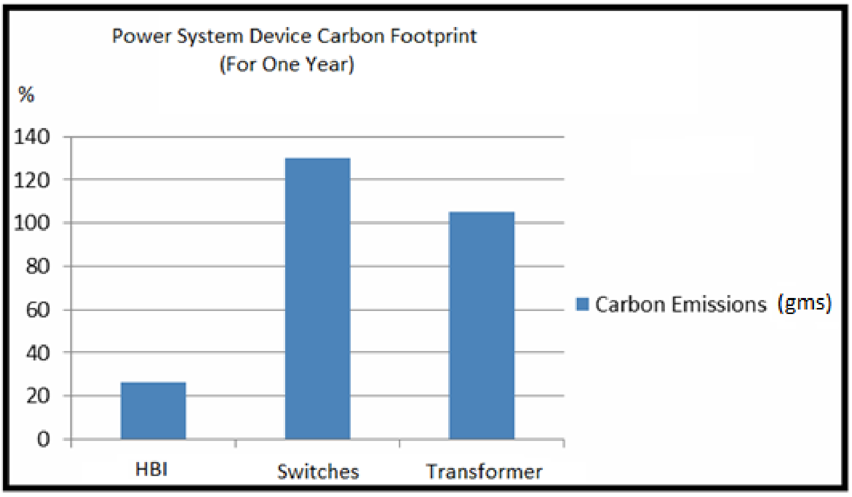

Figure 3: Carbon Footprint observation for power system devices like 5 level H-Bridge Inverter, Switching devices and transformers

We placed carbon trust thermometer with our experiment as mentioned before with respect to figure 1(b). Now, referring figure 3 above, we analyzed that; the carbon footprint level of 5 levels HBI (H-Bridge Inverter) with Microbial Fuel Cell as an input, is much less than any other power system devices like switching equipments or transformers. Till date, there is very less focus over carbon foot printing consequences due to heat or gas generation during various switching activities or due to transformer oil and heat release and chemical actions over various devices material. But, instead of role of transformer in case of inverter voltage step up or step down, the HBI supports to reduce heat generation and helps to maintain "carbon neutral" strategy. This might not reduce large percentage of carbon foot printing but this is also significant to make power system "carbon neutral" at best at its own performance.

VI. Power Quality Performance Evaluation

Simulations of H-Bridge inverter were carried out using Matlab/Simulink. The load used for simulation and experimental results is an RL load (43 [Ω] and 10 [mH]) with a 0.97 power factor, $V_{DC} = 30[V]$ is considered for each cell, and a sampling time $T_s = 100[\mu s]$. A two-cell five-level inverter has been considered to test the proposed interface control algorithm. (verify calculations)

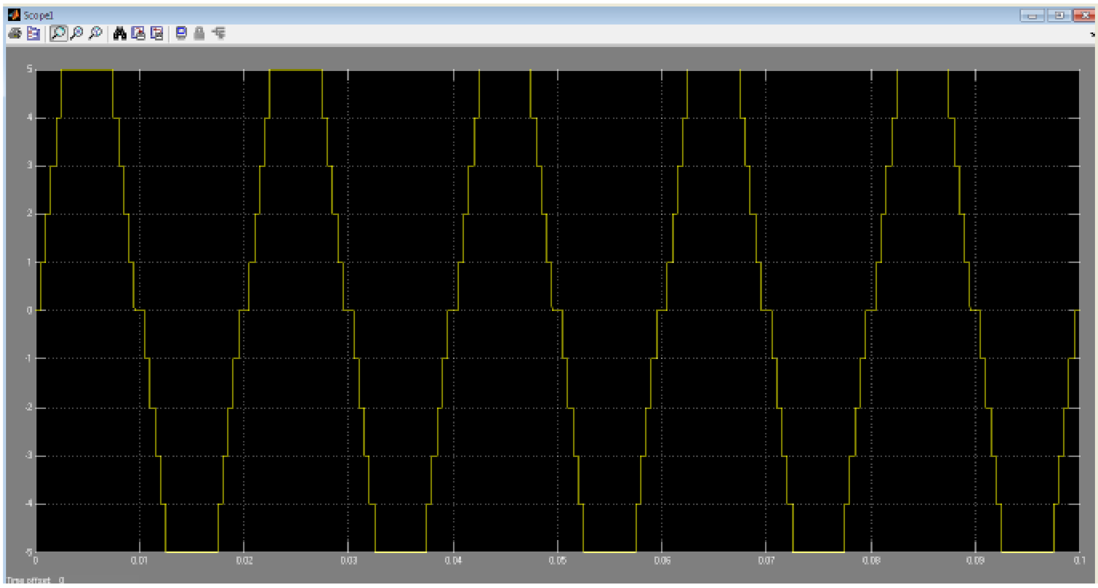

Figure 4. Load current in one phase for a step in the reference amplitude.

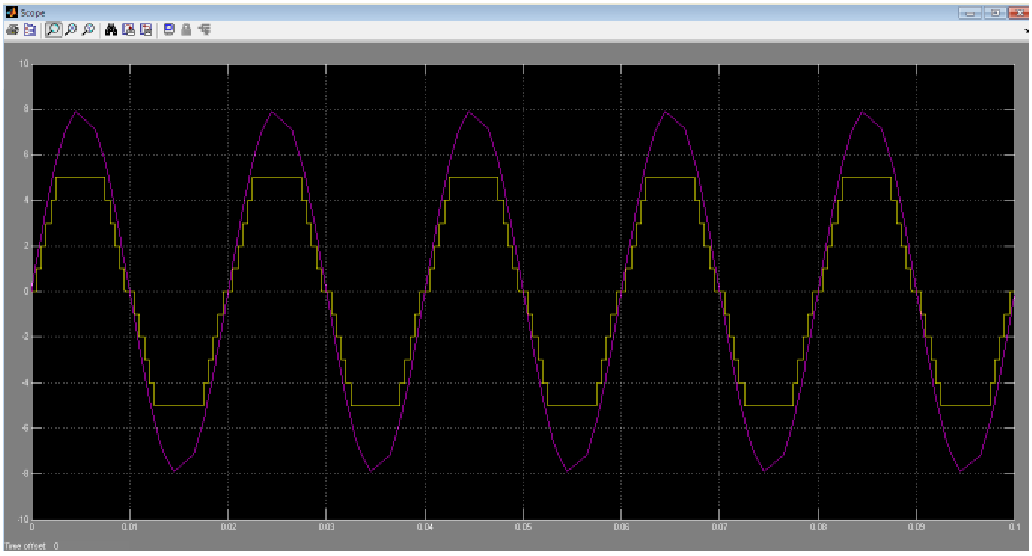

Fig. 5. Inverter voltages for a step in the amplitude of the reference current

The impact of the interface current management for the part of the amplitude with the reference point current is demonstrated in Figure 4. It is shown in Figure 5 that both approaches, contemplating all vectors along with the suggested approach with a decreased number of vectors, include excellent reference point monitoring.

It might be noticed in the comprehensive view with the step transform instant, this revealed in Figure 5, that reference point monitoring of the approach only using the 5 adjoining step responses is a little bit performance degrading as compared to considering the 20 step responses which completes one cycle. This variation need to consider while power quality analysis because the suggested approach will not enable major alterations in the actual test end result voltage. Whenever all vectors step responses are believed, excessive voltage step alterations are feasible. On the other hand, whenever only adjoining (starting from zero reference level) voltage vectors are viewed, voltage alterations are restricted to a single level in the course of each and every testing time period. This particular tradeoff among a small decline in the active functionality as well as the enhancement in electrical power quality is just not a poor attribute. However, for high-power electric devices, the decrease with the values of dv/dt significantly enhances the electric device lifespan, even though the little decrease in active response is hardly recognizable a result of the inertias in the load.

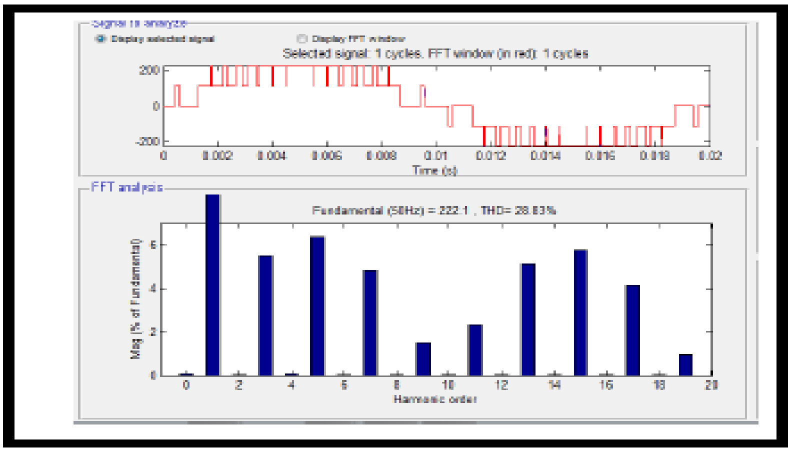

Figure 6: H-bridge multilevel inverter using carrier modulation.

It might be noticed that in case the normal mode voltage is not thought to be in selecting the suitable voltage step, the output from the inverter voltage is just not identical as well as the common-mode voltage. In comparison, whenever repetitive occurrences are removed by choosing voltage vectors along with reduced common-mode voltages and while using subset of adjoining reference level steps, the inverter voltage waveform is identical, and the common-mode voltage is significantly lessened using carrier modulation, as depicted in Figure6.

Because the suggested approach is dependent on a type of load, the consequence of flows within the parameters of the type has been analyzed. As a result of nonlinear controller characteristics, isn't feasible to accomplish effective analytical findings about robustness. The actions of such technique with distinct flows within the inductance have been examined applying simulations. It might be noticed that, despite having significant flows, the load current is governed even though an alteration in the ripple is seen in the event the inductance value is overestimated.

The transitioning consistency in these kinds of interface controllers is adjustable. On the other hand, it is restricted to at the most 50 percent the testing consistency. However, because the testing rate of recurrence is $f_s = 5kMz$, the changing frequency is restricted to 2.5 kHz. The standard changing rate of recurrence has been calculated for various running circumstances. In case a decrease changing frequency is essential, it's possible to lessen this by considering a cost factor towards the transform of the changing state, as introduced in [27].

VII. Conclusion

Carbon foot printing has seemed to be a powerful as well as well-known indication of the GHG strength of any task or organization. Because of its crucial role in elevating attention concerning accountability in the direction of global warming, researchers along with policy makers are attempting to apply it to be an operations tool. Even so, its application within the energy generation (renewable) sector is still constrained. A standard technique is necessary to deal with the emissions associated with eGRID, emissions linked to energy generation resources, along with other power quality pursuits. As a result of prevalent variations in energy generation routines around the globe, it is important to obtain guidelines on selecting limitations along with the development of ideal power quality units.

Additionally, there is possibly a direct requirement for uniformities in GHG evaluation approaches. The possible lack of sector-and region specific emission factors for essential eGRID inputs enhance the uncertainty. The standard approach ought to tackle how to cope with substitute scenarios. On the other hand, these kinds of research characterize the contribution of energy policy practices in a better way than purely emphasizing power quality enhancement device's GHG emissions, carbon sequestration, or energy intensity independently.

Prototype Carbon Footprint Control criteria for H-Bridge multilevel three-phase inverters have been introduced. The suggested approach takes subset of all feasible voltage vectors so as to decrease the volume of computations and ensure it is well suited for execution within a typical control program. This technique might be used on any kind of multilevel inverter having a large number of ranges and transitioning states.

The particular recommended interface management provides excellent reference point monitoring and decreased common-mode voltages, which has a rapid computation formula. Also, taking into consideration the adjoining step responses, merely 5 estimations need to be determined, in spite of the number of stages of the inverter. The suggested formula needs exactly the same number of computations as the management of the two-level inverter. The choice among the adjoining step response voltage vectors powerfully decreases the dv/dt at the load area, although merely a little bit impacting the active effectiveness. This can be a cost-effective tradeoff when contemplating its application in high-power electric motor devices, in which H-Bridge inverters are employed. On the other hand, the suggested management approach can be simply expanded to feature further specifications. The suggested management approach may also be used on various other multilevel converter topologies. This approach is definitely falls under soft-switching which is helpful to reduce carbon foot printing as this approach produces very less heat. Author feels it is the responsibility of every researcher that he/she must consider effect of his/her experimentation over carbon foot printing while making improvements in power quality.

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