AN EFFICIENT PI CONTROLLER BASED LLCL POWER FILTER WITH RESONANCE OPERATION

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ABSTRACT

This paper implemented the new technology for the grid-tied voltage source inverters with higher order power filter that is an LLCL filter. The LLCL power filter consist of a conventional LCL filter with a small branch loop inductor component is associated to the capacitor. Basically it can regulates the operating frequency corresponding current harmonics much effective than the conventional LCL filter also decreases the volume and size of the usage of inductance component in the filter. In this we are additionally proposed the total harmonic distortion (THD) to compensate the harmonics will efficient manner. In this the usage of inductance is less than the conventional LCL filter then the characteristic resonant frequency is increases it leads to improve the inverter performance and control. The LLCL component design and the specifications also explained the conventional LCL filter and the implemented LLCL in detailed manner. The Simulink model results are presented in the MATLAB/SIMULINK for the developed paper.

Index Terms: Grid Tied Voltage-Source Inverter, LLCL Filter, Switching Frequency Harmonics, Series Resonant Converter and the Total Harmonic Distortion (THD)

I.INTRODUCTION

Sincenon-conventionalenergy production is improving more and more concentration, the grid-tied inverter has been extensivelyused. A low-pass power filter is frequently insertedconnecting a voltage-source inverter (VSI) and the grid to control the unnecessary current distortions, which are the majorityfrequentlyaffected by the sine pulse width modulation (PWM) control strategy, to inject the additional required voltage into the point of relationship.

Appropriate to the escalatinginvestment of copper, many procedures have been selected to cut down the cost of the power filter. One effective way is to raise the switching frequency of the inverter anywhere the solution positivelybased on the semiconductordevice apparoachment and expenditure. For example, a SIC device can trigger with a much larger frequency than the similar power to the ratio silicon device performance does, but with a much high cost.

A differentcalculatedconcentrated on special technologies or modulators. In a dual stageoperation technique time-sharing inverter was proposed, annoying to make use of the good quality of the low-voltage operating device to get higher sampling frequency. In dual-mode time-sharing control arrangements for single- and 3-phase inverters, correspondingly.

These wereimplemented to exploit the modulation index range and decrease the output power filter apparatus size. Nevertheless, it works the technologies or monitors much higher to difficult, leading to loss of consistency. Additionally, it is very complex for a dual-mode time consideration of sharing type procedure of inverter to mitigate the distortions or reproduce reactive power to the grid.

The majority common explanation is to employ a third-order *LCL* filter in its place of a first-order *L* filter. Checked with the first order filter*L*, the *LCL* filter can maintain the grid inter association principles with appreciablyless size and price, particularly for featured applications above some kilowatts, except it strength be more complicated to keep the system stationary. Furthermore, chosen the elements of an *LCL* filter are also a supplementary complicated development in dissimilarity to an *L* filter. Occasionally, it is tricky to control the parameters of output current ripple elements sourced by insulated gate bipolar transistor power electronic components (IGBTs),switchedoperating voltage troubles, volt ampere reactiveparameters, and the resonance circuitoperating Switchingfrequency. In this suggested paper, an advanced high-order power filter is adopted, called as*LLCL* filter, is developed. Depended on the conventional*LCL* filter, a less amount of inductor is selected in the branch loop parameter of the capacitor, considering a series resonant control strategy at the sampling frequency. It can, predominantly, regulate the operating-frequency current rippled contentsparameters much effective than the developed*LCL* filter, reduces the total performed of inductance and there it happens to reduction in size. First, the operation principle of the *LCL* filter to compensate the harmonic currents ripples is selected. Next, the implemented*LLCL* filter is explained and discussed, and sustained with an opening on how to develop an *LLCL* filter. The practical experiments of the *LCL* and *LLCL* filters are carried out and checked and clarified. In this we are connected total harmonic distortion control technique to mitigate the current ripple elements effective manner.

II.PRINCIPLE OF THE TRADITIONAL LCL FILTER

The correspondent circuit of an *LCL*-filter-depended single-phase grid-connected Voltage Source Inverter is demonstrated in Fig.1. The inverter produced output voltage and current are denoted as *ui*and *i*1 , and the grid side voltage and current are noticed as *ug*and *ig*. The sampling frequency is given as *fs* (in hertz) or *ωs*(in radians per second). It is unspecified that the power connected grid is anatural ideal voltage source, i.e., zero impedance conditions, to supply a steady state voltage at the minimum fundamental frequency ranges of 50 or 60Hz. When the single-phase full-bridge VSI is operated under the condition of uni polar, sine-triangle, and asymmetrical regular sampled Pulse Width Modulation, its developed voltage *ui*(*t*) can be derivative as

$$u_i(t) = U_{dc}\cos(\omega_o t) + \sum_{k=1}^{\infty}\sum_{n=+1}^{\mp\infty}\frac{2U_{dc}J_n(K\pi\alpha)}{K\pi}\sin\left(\frac{n\pi}{2}\right)\cos(K\omega_s t + n\omega_o t)$$

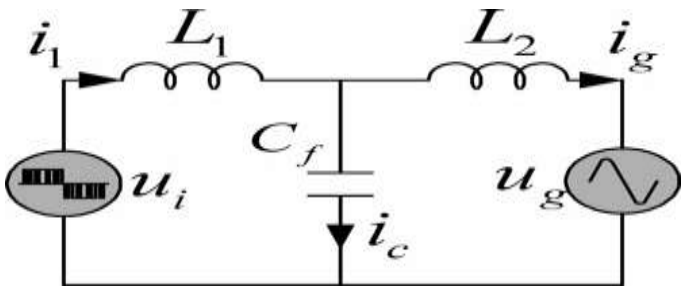

Fig.1Equivalent circuit of an *LCL*-filter-based single-phase grid-tied VSI

where *α*specifies the modulation ranges of index,*U*dc is express the dc link voltagequalifications, *ωo*is the required operating minimum fundamental frequency in the units of radians per second, and *Jn*(*x*)is forwarded as the integrals of the Bessel mathematic functionexplaines, which is expressed as *Jn*(*x*) = (1/*π*) _ *π* 0 cos (*nπ* − *x* sin *τ*) *dτ*, presentation the different sideband harmonic amplitude. The inverter produced output impedance can be discussed as

$$Z_o\ (J\omega) = \frac{u_1\ (J\omega)}{i_1\ (J\omega)} | u_g(J\omega) = 0\omega \neq \omega_o = \frac{L_1\ L_2\ C_f\ (J\omega)3+(L_1+L_2)JW}{L_2\ C_f\ (J\omega)2+1}$$

Depended on the harmonic ripplescommendation produced it is sensible to deduce the grid-side current *ig*as the "natural ideal" steady state current only at the minimum frequency. Otherwise, the branch circuit parameters of inductor *L*2 can be seen triggered offalthoughselecting the belongings of the inverter high- ordered frequency harmonic contents. Then, roughly, (2) can be rewritten as

$$Z_o\ (J\omega) | \omega \neq \omega_o\ \cong L_1\ J\omega + \frac{1}{C_f\ J\omega}$$

Additionally, in an *LCL* filter, 1*/Cfjω* _ *L*1*jω* is normally true around the sampling frequency or very high. Then, (3) can be calculated as

$$Z_o\ (J\omega) | \omega \neq \omega_o\ \cong L_1\ J\omega$$

And the generated harmonic magnitudes in the inverter-side current *i*1 can be resultant as

$$||I_{AM}|\quad |\omega \neq \omega_o\ = \frac{U_{AM}(n,k)}{Z_o\ (J\omega)}$$

Where the magnitude of inverter output distortioned voltage *U*AM (*n*, *k*) is

$$U_{AM}(n,k)\ |k = 1,2,\dots \infty, n = \mp 1 \mp 2 \dots \mp \infty = |\frac{2U_{dc}J_n\ (K\pi\alpha)}{K\pi}\sin\left(\frac{n\pi}{2}\right)|$$

Fig. 2 represents the main harmonic current ripples of the inverter produced output current below the condition of that the modulation index range consideration *α* is 0.9, the dc link addition injected voltage *U*dc is 350V, maximum inverter produced current harmonics is 31.5%*I*ref (where *I*ref is the required reference minimum peak current), and the operating switching frequency *fs* is 20 kHz. It can be observed that the highest harmonics of inverter produced current are approximately the sampling switching frequency. so, the grid-side major element inductor *L*2 and the associated in paralleled the branch element capacitor *Cf*are both are mainly restricted by the harmonics considered the operating frequency.

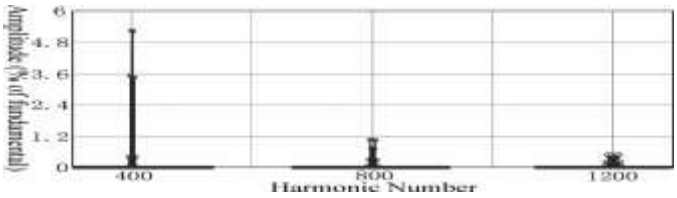

Fig. 2.Main Harmonic Current Spectrum of Inverter with Unipolar Modulation

Assume that the impedance is maintains as zero in the branch element based of the capacitor reaches at the sampling frequency, the grid-tied inductor *L*2 should be minimizeddepended on the double of the operating frequency current reduction from the inverter side converter to the grid side arrangement, which is very

favorable to scale the grid-tied converter inductance down. To accomplish this, a new advanced order power filter will be implemented in the further discussions.

III.PROPOSED LLCLFILTER

To accomplish the zero impedance of the capacitor branch elementscircuit at the working frequency, the under practicalideal series resonance control strategy demonstrated in Fig. 3 could achieve well. In that situation, a new high-order power filtersproposed, called as the *LLCL* filter, is specified and design the diagram as illustrated in Fig. 4. Checked and verifiedwith the *LCL* filter, a less inductor is preferred in the branch loop parameters of the capacitor, including an *Lf* –*Cf*series significant circuit at the working frequency, and its inductance is generally much lower than that of *L*1 or *L*2.

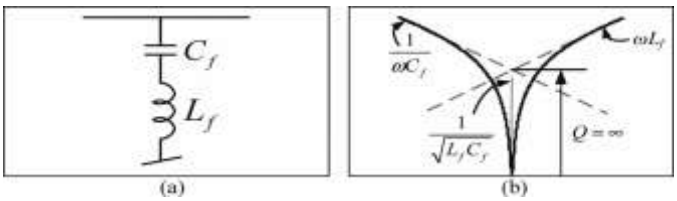

Fig. 3 (A) Second-Order Series Resonant Filter. (B) Second-Order Filter Impedance Transfer Functions

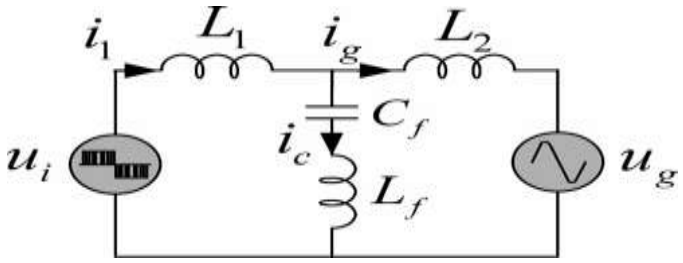

Fig. 4.Schematic Diagram of the *LLCL* Filter

Considering that the grid is an practical ideal sinusoidal methodology of voltage source requirement, the transfer functions parameters *i*1 (*s*)/*ui*(*s*) and the calculated transfer functions *ig*(*s*)/*ui*(*s*) of *LLCL* filter be able to be process simultaneously, correspondingly, Calculated as

$$G_{u_1 \to i_{l_1}}(s) = \frac{i_1(s)}{u_1(s)}|u_g(s) = 0 = \frac{(L_2 + L_1)C_f(s)2+1}{L_1 L_2 C_{f+}(L_1 + L_2)L_f C_f(s)3+(L_1 + L_2)s}$$

$$G_{u_1 \to i_g}(s) = \frac{i_g(s)}{u_i(s)}|u_g(s) = 0 = \frac{L_f C_f(s)2+1}{L_1 L_2 C_{f+}(L_1 + L_2)L_f C_f(s)3+(L_1 + L_2)s}$$

If the branch element inductance of *Lf* is set zero, then the transfer functions values are of *LCL* filter has capability be also deliberated. Fig. 5 gives the transfer functions values of *i*1 (*s*)/*ui*(*s*) and *ig*(*s*)/*ui*(*s*) of in cooperation*LLCL* filter and *LCL* filter although all the other parameters are the equivalentexcluding for *Lf* .

It can be observe that within half of the sampling frequency corresponding, an *LLCL*-filter-depended grid-tied VSI has approximately the equal frequencyoperationcorresponding characteristic of an *LCL* filter. That is to converse, contrasted with the *LCL* filter, the complementary inductor *Lf* of the *LLCL* filter will notconvey any additional control complexities. Additionally, a less value of the grid-tied connected inductor *L*2 of the *LLCL* filter might be advantageous to broaden the manage bandwidth.

3.1 Circuit Description

Basically in this paper we are proposed an advanced LLCL power filter is proposed for the single phase inverter. In this the supplied direct current (D.C) voltage is generates to the single phase bridge inverter technology. Then the inverter is performingto convert the required operation and it has to be generating the ac output. But every inverter does not produce the proper ac voltage for this cause we have to utilize the power filter to compensate the harmonic content in the generated output.

Here in this we are implemented the LLCL filter is connected to compensate the harmonics in the generated pulsating ac voltage. In this the connection of LLLCL filter is discussed in this one inductor is series connected to the capacitor to compensate the harmonics effective manner and it reduces the voltage stress in the inverter side. In this we are placed the total harmonic distortion technique also to mitigate the distortions very clear manner.

In the ideal systems the transfer functions are linear and time –in variant systems these are passing through the signals in the non ideal ,non linear, variable load conditions then it generates some additional harmonic contents in the innovativefrequencies. The foremostargument of the THD is to sustain the sine wave with purified ripple free output will be inhabited. It is divergent as the quantity of a position of rout mean squares of the higher order harmonic content frequencies to the first harmonic content frequency of the signal.

The designed model utilizes the pulse width modulation control strategy to produce the firing pulses to the inverter. The PWM performs very accurately to produce the required sufficient voltage to the grid side.

IV. CONCLUSION

In this implemented paper, the basic principle of the traditional *LLCL* filter is developed. It can be observed that the major high-order distortion current currents ripples mostly presented around the operating switching frequency. Considering this, an advanced technology of low-pass higher order power filter with series connected branch elements*Lf –Cfforms a*series resonant circuit, called as *LLCL* filter, has been implemented. In difference to the existed LCL filter, the proposed LLCL filter has almost zero impedance at the operating sampling frequency and can powerfullycompensate the harmonic currents ripples in the specified switching frequency.

The essential parameter chosenpossibility and a components development process of an *LLCL* filter are also discussed. It can be observed that the grid-tied inductor *L*2 of the *LLCL* filter is essentiallydetermined by the distortions currents throughout the surface the double of the working frequency as a substitute of those considered area the operating frequency, which generates in decrement in the total branch loop inductance and volume declinement contrast with the *LCL* filter. In this we proposed the THD control technique to produce the effective and required sufficient voltage to the load side.

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