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GRID CURRENT HARMONICS REDUCTION IN OPTIMIZED LCL FILTER DESIGN FOR MICRO GRIDS

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ABSTRACT

It is essential to maintain the power quality in any type of the grid, but pronounced seriously in case of micro grids because of basic oscillatory nature of natural environmental power. The research aims at maintaining the harmonic level through a proper closed loop control system with sufficient optimization in gain parameters of the controller. The project aims at a new method of measuring harmonics in micro grid inverters, than the existing measurement techniques. The proposal is to detect the harmonics and it amplitude at the originating point. Finally, the detected harmonics are injected into the grid to reduce the harmonic content in final output of the microgrid. The proposed model can be used to to get a fixed voltage at any desired operating point. The major task in such design is to reduce the current harmonics present in the power delivered to the DC loads. In the existing system, it claims up to 200% of THD, whereas in the proposed system it is as less as 3.71% of THD. This method does not require any online replacement of lumped components during the operation of the circuit. Moreover, extended phase shift in the gate pulses generation gives a better reduction in the current harmonics.

INTRODUCTION

A harmonic of a wave is a component frequency of the signal that is an integer multiple of the fundamental frequency, i.e. if the fundamental frequency is f, the harmonics have frequencies 2f, 3f, 4f., etc. The harmonics have the property that they are all periodic at the fundamental frequency, therefore the sum of harmonics is also periodic at that frequency. Harmonic frequencies are equally spaced by the width of the fundamental frequency and can be found by repeatedly adding that frequency. For example, if the fundamental frequency (first harmonic) is 25 Hz, the frequencies of the next harmonics are: 50 Hz (2nd harmonic), 75 Hz (3rd harmonic), 100 Hz (4th harmonic) etc. IT is well known that voltage or current harmonics generated by power converters can cause various problems to other equipment connected to the common ac lines

However, the grid background harmonics are not considered in the traditional SHE PWM. In a current source rectifier (CSR) system, due to the use of an input LC filter, the grid background voltage harmonics (such as fifth or seventh harmonic) could be amplified by the filter, which results in a high distortion of the line current, although the grid voltage harmonics are low.

HARMONICS MEASUREMENTS

Harmonics provides a mathematical analysis of distortions to a current or voltage waveform. Based on Fourier series, harmonics can describe any periodic wave as summation of simple sinusoidal waves which are integer multiples of the fundamental frequency. Harmonics are steady-state distortions to current and voltage waves and repeat every cycle. They are different from transient distortions to power systems such as spikes, dips and impulse

$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$

A pure sinusoidal voltage is a conceptual quantity produced by an ideal AC generator built with finely distributed stator and field windings that operate in a uniform magnetic field. Since neither the winding distribution nor the magnetic field are uniform in a working AC machine, voltage waveform distortions are created, and the voltage-time relationship deviates from the pure sine function. The distortion at the point of generation is very small (about 1% to 2%), but nonetheless it exists. Because this is a deviation from a pure sine wave, the

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deviation is in the form of a periodic function, and by definition, the voltage distortion contains harmonics.

EXISITING SYSTEM

The inverted voltage is coupled to the secondary of the topology via an SMPS transformer made of ferrite core. This transformer offers a very low impedance to the high frequency in the order of 200 KHz. This high frequency basically introduces harmonics in the output current as well due to the stray capacitances and stray inductances of the power switch. Hence the existing model is very inefficient in terms of harmonic removal.

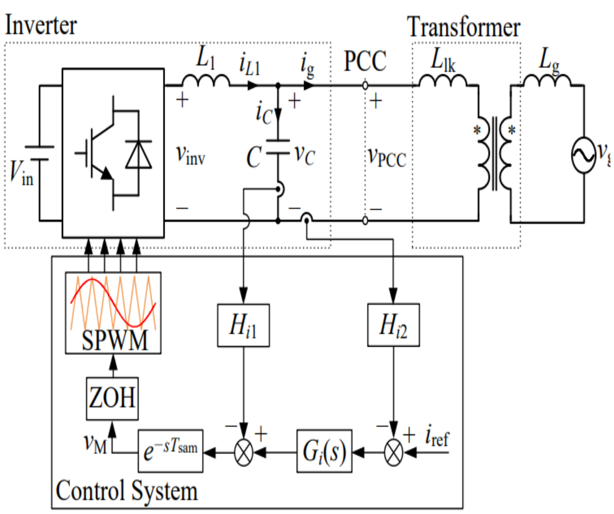

Fig: 1 Existing architecture

The system consists of a microgrid source that produces a DC power from an array of solar panels. The same is applied to a three phase inverter to make it as alternating current. At this stage, harmonics are created due to the inverter switches and high frequency of the gate signals. Due to this the harmonic are injected to the main grid too. Therefore, the microgrid harmonics at the point of common coupling (PCC) are applied to final AC loads and the macro grid too.

Therefore, LCL filter is applied to reduce the reduce the harmonics at the output. The method is to reduce the harmonics by injecting the harmonics in anti-phase by properly estimating the harmonics including the magnitude and angle using Fast fourier transform.

After estimating the harmonics the same in injected in the line in the parallel circuit that eliminates the harmonics when visualized at the load point.

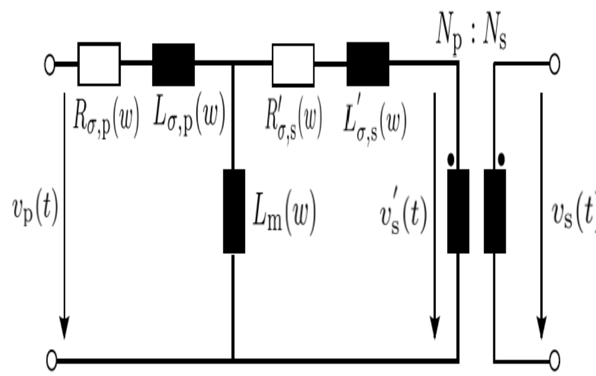

Fig: 2 Equivalent circuit of LCL filter

Table 1 Parameters used in existing system

Parameter		Value
Primary bridge ..		
..DC bus inductance (parasitic)	L_{DC}	200 nH
..DC bus capacitance	C_{DC}	TBD
..Bulk source capacitance	C_{src}	4.4 mF
AC link coupled inductor	L	103 μH
	R	0.4 Ω
Primary DC bus voltage	$2V_{p,DC}$	50 V
DC-DC bus voltage ratio	d	0.8
Switching frequency	f_{sw}	20 kHz

In addition to say, the operating current is in the order of less than 2A, which is practically very less value of load. In practical cases the current would be in the order of 5A and above.

MATLAB SIMULATION

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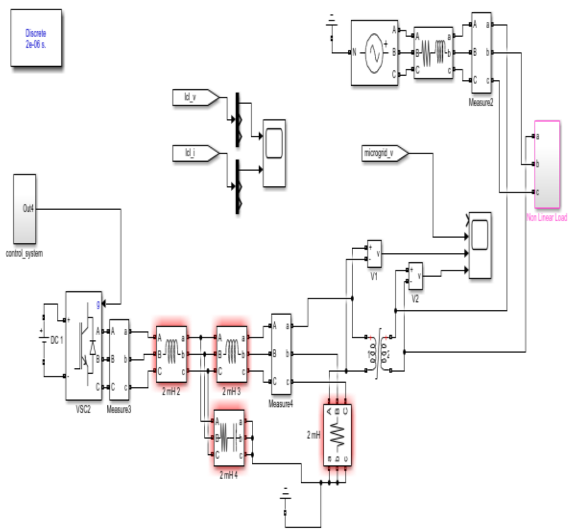

Fig: 3 Simulink model of DC to DC converter

The Simulink model implemented in matlab 7.13 is shown in the above figure. This consists of H bridge at both inverter section and rectifier section. The PWM pulses are applied separately to the rectifier and inverter. However, the rectifier section is additionally controlled by a PI controller to maintain a stable output DC voltage. Inverter and Rectifier are coupled through a high frequency coupling transformer. The switches in H bridge are operated on diagonal wise. When one diagonal switches is ON, the switches in other diagonal are OFF. The switched waveform obtained at final stage is filtered using a DC capacitor.

Current with harmonics

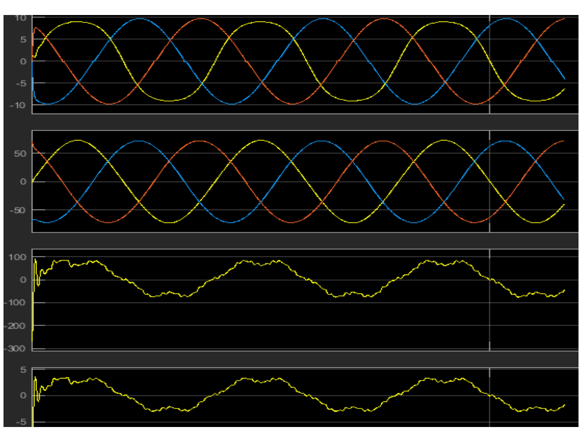

Fig:4 DC Current waveform with harmonics

The output reveals that the current harmonics are more and the pulsating DC current itself has higher harmonics and vibrating in the range of +10 to -10 A. Though the peak to peak value is in the order of 20A the average DC value of the current is the order of 1.5 A as seen in the above simulation output. The task is to increase this magnitude as well as without harmonics. The output reveals that the voltage harmonics are existing and moreover the output is also not stable. It is seen that the output DC voltage in the order of 210 V, which is not stable and pure DC line.

THD in existing topology

THD Before injection of anti harmonics

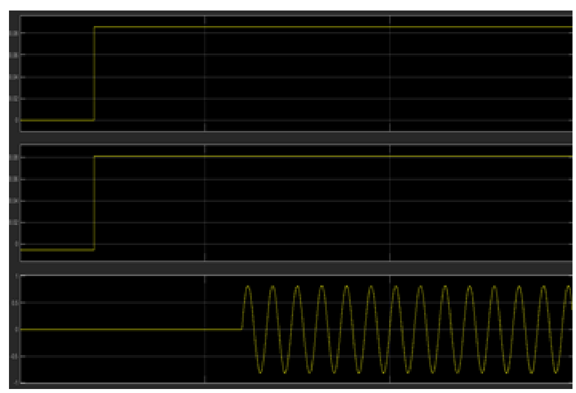

Fig: 5 Current harmonics

FFT analysis is done in matlab by using the power GUI tool box. The fundamental is set as 50Hz, and the harmonics are measured up to 24 harmonic orders. A total THD of around 261 % is obtained in the existing system. Maximum frequency is set to 1200 Hz, beyond which the harmonics have no impact, because of negligible amplitude at higher harmonics.

The virtual impedance concept has been increasingly used in power converters or active damping of the converter filter circuit converter output power flow control system harmonics compensation etc. In different applications, virtual resistance, virtual inductance, virtual capacitance, or

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combination of them has been used. Generally, the virtual impedance is realized through the control of a power converter, and it does not involve the physical loss as in real impedance.

Combining the virtual impedance concept with the recently proposed SHC PWM scheme, an improved SHC scheme can be developed, and is called virtual impedance SHC (VI-SHC) scheme. In the proposed VI-SHC scheme, the extracted harmonic in the line current is used to realize a virtual impedance at the harmonic frequency. Virtual impedance variation is detected and through that the presence of harmonics is detected in current only.

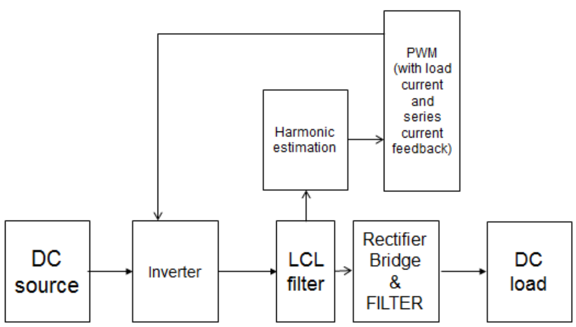

Fig: 6 Architecture with LCL filter

The system consists of a microgrid source that produces a DC power from an array of solar panels. The same is applied to a three phase inverter to make it as alternating current.

At this stage, harmonics are created due to the inverter switches and high frequency of the gate signals. Due to this the harmonic are injected to the main grid too. Therefore, the microgrid harmonics at the point of common coupling (PCC) are applied to final AC loads and the macro grid too.

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After estimating the harmonics the same in injected in the line in the parallel circuit that eliminates the harmonics when visualized at the load point.

1) The proposed VI-SHC scheme compensates the system background harmonics using the line current measurement instead of the source voltage in the SHC scheme. Therefore the VI-SHC PWM is more practical in the real applications, since the voltage distortion is usually very subtle for accurate measurement.

2) As the PWM output in a CSR system is directly related to the line current, the VI-SHC method is essentially a closed-loop compensation scheme by feeding back the line current harmonics. Therefore, it does not require the detailed and precise system parameters for the derivation of the system transfer functions.

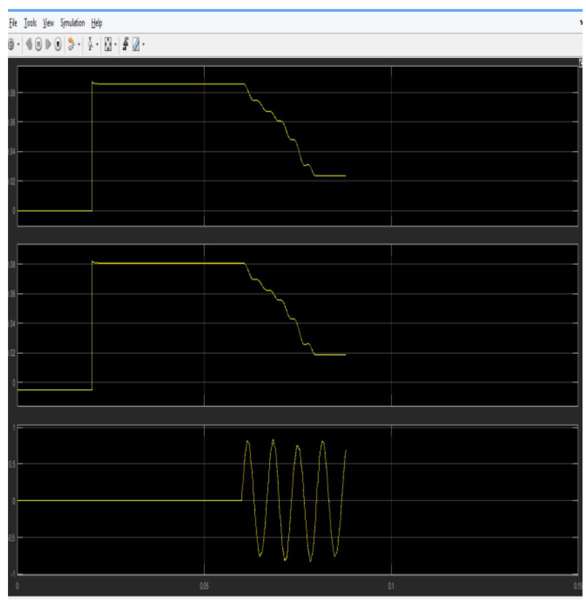

Fig: 7 THD after filter

Table: 2 Circuit constans

Parameter	Value
Rated power	100W
Rated voltage	230V
Fundamental frequency	50 Hz
DC link voltage	200 V
PWM switching frequency	10KHz
DC current	~2A

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Both virtual impedance and FFT based analysis is done and both are compared. This is a new method to detect and eliminate both voltage and current harmonics.

$$Ish = \frac{Vsh}{Rs + j\omega hLs + Zth + Zvh}$$

TPS control includes multiple operating modes with respect to the buck/boost and various operating conditions such as heavy-load and light-load cases. Three phase shifts are adopted in the TPS control and the corresponding phase shift ratio are symbolized as D1, D2 and D3. D1 is the phase shift ratio between the diagonal control signals of the same bridge, for instance, between the gate signals of Q11 and Q14; D3 is the phase shift between the primary control signal and the corresponding secondary gate signals, for instance, between the gate signals of Q11 and Q21; D3 is the phase shift between the gate signals of Q11 and Q24. In the forward mode, the transformer primary voltage VT1 is leading to the transformer secondary voltage VT2 so that the power flows from V1 to V2. Considering the volt-second balance of the inductor current iL in one switching period, the current value at switching intervals 1 φ, 2 φ , 3 φ and π for different operating modes of TPS control can be obtained.

$$I_b = V_1/(4L_s f_s),\ P_b = dV_1^2/(4L_s f_s)$$

Where f_s is the switching frequency, d is the voltage conversion ratio. The variables of d, V1, fs and Ls affect only the magnitude of P_o. The phase-shift group determines operating modes and the amount of output power.

CONCLUSION

In this paper, an impedance shaping method is proposed with virtual impedances, and the current control loop can be designed independently. The implementation and parameter design of the virtual impedances are studied under the practical considerations. With this proposed method, the grid-connected inverter can work stably over a wide range of the typical inductive-resistive grid impedance and exhibit strong rejection ability of grid voltage harmonics. Experimental results from a 6 kW single-phase grid-connected inverter confirm the effectiveness of the proposed method. The system gives fine output in one direction, where the LCL filter does the automatic estimation of harmonics and filtering of the same and able to drive a DC load with few hundreds of watts power capacity. The harmonics generated in the proposed topology is as less as 3.71% as seen the Simulink outputs. Power loss in the form of harmonics is reduced enormously in the proposed system. Hardware implementation could successfully eliminate the harmonics present in the DC output at the load side.

SIMULATION PERFORMANCE COMPARISON

Parameter	Current state of art	Proposed work
THD (%)	> 200%	3.71 %
Reduction method	Using additional components put in circuit	LCL
Frequency (kHz)	200	10
Harmonic Order	24	>24 is possible
Stability analysis	Not done	Stable at 0.06 s

FUTURE SCOPES

The performance of all these algorithms can be evaluated in the over modulation zone. Analytical evaluation of harmonic distortion for multilevel inverters can also be carried out. Moreover, SVPWM based techniques can be developed for inverter switching at much higher frequencies and hardware implementation can also be done. All the proposed algorithms in this thesis are for time-invariant systems. Therefore, it is recommended to eliminate harmonics for time-variant systems.

Further to reduce the switching losses of the inverters, discontinuous pulse width modulation algorithms have to be proposed. The THD may be reduced to less than 4%

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