



# **RVG FOR ON-GRID AND OFF-GRID DISTRIBUTED GENERATING UNITS THROUGH LC FILTER DESIGN**

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## **Abstract**

**This paper deals with design criteria for LC low pass filter for on grid and off grid distributed generation units by adopting reference vector or voltage generation. The aim of this procedure is to provide guidelines and component selection criteria for reducing the inverter output switching ripple in order to limit the interaction with the control algorithm and to increase the filter stability. In the RVG technique the missing voltage at the load side is generated by using PI controller, Signal generator and PWM generation technique.**

**Index Terms: RVG, DC – DC Boost Converter, Bidirectional converter.**

## **1. INTRODUCTION**

The distributed generation systems are accomplished by using renewable energy generating units (e.g., photovoltaic arrays and wind turbines), which have relatively low power rating and are suitably connected to the power grid at the voltage level of the electricity distribution network so that the significant investment in electric transmission infrastructure can be substantially reduced. However, due to the intermittent nature of the renewable energy sources and the desire for generating operation with maximum power point tracking, an energy storage is usually needed, and thereby, the various electric power sources are operated in parallel against a common dc link by means of

power electronic converters, as schematically shown in Fig. 1. In the distributed generation units the electrical energy generated is in form of DC but in actual use we largely use the AC. Hence, a dc-ac converter with four-wire output is used for connecting the generating system to the distribution network and the user loads, being such a converter required to provide both active and reactive power output depending on whether it is operated on grid or off grid. In this type of generation the end user having interest to use self-produced energy which is initially costly but after ones installed it is very cheap and ecofriendly. Whereas the excess power generated is sold to the public utility and the money can be earned which will be beneficial to households. In case if energy produced by the distributed generation is less than the actual load then the remaining energy can be taken from the utility to achieve required demand. On the other hand, if the grid fails, the generating system is disconnected from the utility grid, and the dc-ac converter is required to provide the electrical supply for the local loads. In the actual modeling the output of the DC-AC converter with actual harmonics production can be analyzed so that design of LC filter can be done accordingly. It is possible to divide the spectrum of the converter output voltage into two main portions, i.e., the one related to fundamental frequency harmonics (low frequencies) and the one that concerns the switching harmonics (high frequencies).

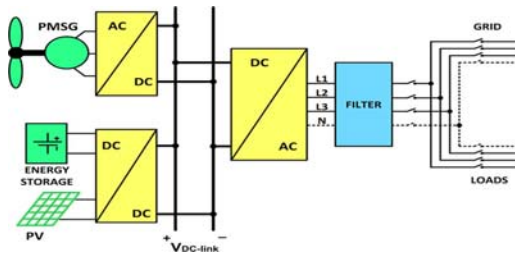


Fig.1. Distributed generation units for ON & OFF grid application

The first portion having the frequencies like fundamental frequency e.g., the 50-Hz component in grid tied mode.

The second portion contains the frequencies other than fundamental component that are undesirable to us and which can be eliminated or filtered. As it is well known, a filter is needed for removing or, at least, for reducing the high-frequency content in the output voltage waveforms, thereby allowing only the low frequencies to pass through. To date, among the various filter configurations that have been proposed in the literature with the goal of reducing the harmonic content due to the converter switching, the most widely used schemes are based on the LC and LCL filter topologies. The LCL filter type is generally used in for grid tied applications, since the presence of the second inductor makes the filter response more immune to grid parameters variation. This filter configuration makes it possible to get an output current ripple extremely low using inductors of relatively small value, compared with those of LC working with similar performances [1].

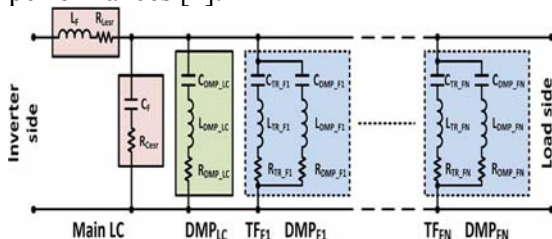


Fig.2. Proposed topology for the inverter output power filter.

The filter configuration derived from the LCL circuit and named as LLCL has been proposed in recent literature [3]. In this configuration, the LCL capacitor is replaced by an LC series circuit, tuned to resonate at the switching frequency. The presence of the LC circuit is intended to provide a near-zero impedance path for the residual switching component flowing through the main inductor. This feature allows strongly reducing the output switching

component when compared with the conventional LCL filter with same component values. However, it causes the reduction in the filter roll off due to the high impedance of the LC series circuit at high frequency. In addition, in the LCL and LLCL filters, the inductor on the inverter side and the one on the grid side have to carry the full line current; even if the inductances value is quite reduced with respect to the LC filter topology, the resulting cost and size are still important. An alternative to the previously described configuration is the LC filter equipped with a tuned trap filter. The tuned trap filter has the LC-series configuration and is tuned at the output current ripple fundamental frequency. This filter is intended to reduce the output voltage switching ripple by giving a quasi-zero impedance path for the residual switching component flowing through the main inductor. This way, similar performance of the LLCL filter can be achieved; however, only one le current sized inductor is used.

Both LC- and LCL-based filter topologies present resonance phenomena at their characteristic frequency. The resonance can be suitably damped through a proper resistor, to be placed either in parallel or in series with the inductor or the capacitor. Conventional schemes show this resistor in series with the capacitor [5-6]. However, when the resistor is selected to obtain similar behavior of the Butterworth-type second-order low-pass filter, the LC roll off at high frequency changes from  $-40$  dB/dec to nearly  $-20$  dB/dec. This drawback can be avoided by using a properly tuned series RLC circuit, placed in parallel connection with the LC capacitor, in order to selectively damp the LC characteristic resonance. In fact, with respect to its resonance frequency, the series RLC circuit shows high impedance at low and high frequencies and impedance equal to  $R$  at its resonance. As a consequence, it is possible to make the damping resistor visible only for a reduced frequency range, without degrading the low impedance at high frequency of the capacitor of the main LC filter and assuring, at the same time, satisfactory damping for the LC filter. Active damping of the natural LC resonance has been investigated in recent literature. The virtual resistor technique acts on the control algorithm parameters in order to adjust the converter internal impedance. However, additional current sensors are required

to perform this task; in addition, control platform advanced performances are essential to correctly operate at the LC resonance frequency. This paper deals with the design procedure of an LC output filter, with either single or multiple tuned trap filters. Suitable damping is achieved by means of a properly sized damping circuit. Each element added to the basic LC filter is designed to accomplish a specific task in order to shape the desired whole filter frequency response.

## II. PROPOSED FILTER ARCHITECTURE

Second-order Butterworth band pass filters were designed using both passive and Q-enhanced single-pole and pole-zero resonators. The zero-pole-zero resonators were not used in filter designs due to die area constraints. Each resonator was designed for a 60 MHz -3dB bandwidth centered at 1.88 GHz, corresponding to the North American PCS transmit band. Three second-order Butterworth band pass filters based on the single-pole resonator structure were designed. The first uses a passive 1 nH single-pole resonator. Simulations predict an insertion loss of 21.8 dB at 1.88 GHz and a -3 dB bandwidth of 150 MHz's. This reduction in the selectivity of the filter is a consequence of the resonator loss. In the other two filters, this passive resonator is Q-enhanced and tuned for 0 dB insertion loss at the centre frequency of the filter. One filter uses the Q-enhanced resonator with a 1 mm D-FET. When tuned to 0 dB of insertion loss, simulations confirm a -3 dB bandwidth of 60MHz and predict a current consumption of 23.11 mA at  $V_{ds} = 3$  V. The second Q-enhanced filter utilizes the negative resistance circuit used to Q-enhance the pole-zero resonators in the previous chapter. Again, simulations confirm a -3 dB bandwidth of 60 MHz and predict a current consumption of 17.7 mA at  $V_{ds} = 3$  V.

Two second-order Butterworth band pass filters based on the pole-zero resonator structure were also designed. The first uses the passive 2 nH pole-zero resonator. Simulations of this circuit predict an insertion loss of 27.4 dB at 1.88 GHz and a -3 dB bandwidth of 110 MHz's. The second filter uses the Q-enhanced 2 nH pole-zero resonator from the previous chapter. The effect of compensating the resonator capacitance, due to the capacitance of the negative resistance circuit, can be seen as the zero is shifted higher in frequency when

Q-enhanced. When tuned for 0 dB insertion loss, simulations confirm a 60 MHz -3 dB bandwidth at 1.88 GHz and predict a current consumption of 4.38 mA at  $V_{ds} = 3$  V.

One unexpected and unexplained result of these simulations is that the total current consumption of the two negative resistance circuits in each of these filters is less than twice the simulated current consumption (at the same voltage bias) of the individual Q-enhanced resonators presented in the previous chapter. It is also interesting to note that, despite the passive pole-zero resonators having less loss than the passive single-pole resonator, the filter corresponding to the passive pole-zero resonators has a greater pass band insertion loss than the filter corresponding to the passive single-pole resonator. This is because the 2 nH pole-zero resonators must be more tightly coupled than the 1 nH single-pole resonators to result in the same -3 dB bandwidth. Therefore tightly coupling the resonators will magnify the effects of the resonator loss. Q-enhanced, however, the loss of each individual resonator is reduced prior to coupling, thereby making the Q-enhancement independent of the coupling. Therefore, it is more power efficient to Q-enhance each individual resonator then to Q-enhance the passive filter.

## III. REFERENCE VECTOR GENERATION FOR ON GRID AND OFF GRID

There is no backup or battery for the system. Taking voltage from the grid and using it for compensation but grid voltage cannot be pure sinusoid, it consist of harmonics and therefore corresponding to grid voltage the current cannot be generated. One method for PWM generation is creating truth table for grid voltage and then triangular comparison can be done, but the change in grid voltage affect the truth table. More the values in truth table more accurate will be the signals but then memory required increases therefore a strategy known as Unit vector generation is adopted. In this method the grid voltage is sensed and corresponding voltage is generated whose magnitude is always unity.

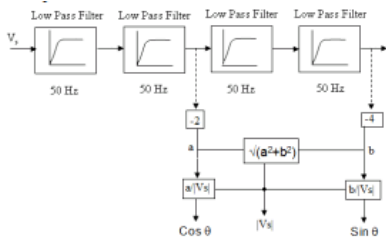


Fig.3. Block diagram for unit vector generation

Fig.3 shows the block diagram for unit vector generation in which the peak value of the grid voltage is sensed by sensing the zero crossing of the cosine wave (i.e.  $\theta$  phase lag with the grid voltage). Each low pass filter has  $45^\circ$  phase difference which create cosine and in phase component.

To produce three-phase load reference voltages are compared with load line voltages and errors are then processed by sinusoidal PWM controller to generate the required switching signals for series APF IGBT switches. Modulation Techniques

The VSI inverters used in the AC drive models of the library are based on two types of modulation, hysteresis modulation and space vector pulse width modulation (PWM).

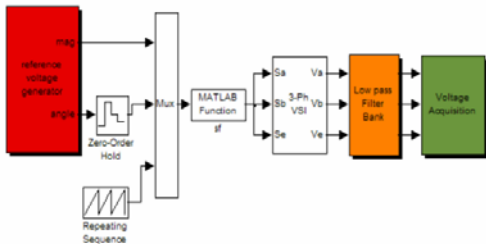


Fig.3.1. Reference voltage generation in the form of vector

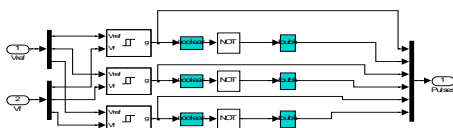


Fig.5. PWM Reference Generation

The hysteresis modulation is a feedback current control method where the motor current tracks the reference current within a hysteresis band. The following figure shows the operation principle of the hysteresis modulation. The controller generates the sinusoidal reference current of desired magnitude and frequency that is compared with the actual motor line current. If the current exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and the lower switch is turned on. As a result, the current starts to decay. If the

current crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. Hence, the actual current is forced to track the reference current within the hysteresis band.

The space vector modulation technique differs from the hysteresis modulation in that there are not separate comparators used for each of the three phases. Instead, a reference voltage space vector  $V_s$  is produced as a whole, sampled at a fixed frequency, and then constructed through adequate timing of adjacent nonzero inverter voltage space vectors  $V_1$  to  $V_6$  and the zero voltage space vectors  $V_0, V_7$ . A simplified diagram of a VSI inverter is shown below. In this diagram, the conduction state of the three legs of the inverter is represented by three logic variables, SA, SB, and SC. Logical 1 means that the upper switch is conducting and logical 0 means that the lower switch is conducting.

IV. UNITS FILTER DESIGN EXAMPLE

We have included MPPT technique, MPPT is conventional technique in the project PV array (photo voltaic array) the input is solar irradiance, temperature.

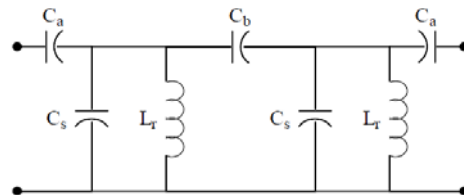


Fig. 7: Second-order Butterworth band pass filter simulation using pole-zero resonators.

Whenever switch is off the voltage across PV voltage plus battery voltage will be added then 159V will come to that DC link. Whenever PV power high at that time the turn on time of duty cycle should be decreased then there is no need to store energy. Whenever voltage goes below 100V then we have to improve to 150V. Whenever voltage goes above 150V then decreased most probably we can't get above, Suppose if we get 130V means 20% we have to increase if we get 140V means 10% we have to increase turn ON point only we have to keep 90% off and 10% on. Whenever we get 75% to 25% should be ON then 75% OFF then we get 150V here how we overcome loss that is only MPPT technique. MPPT will adjust the duty cycle of switch and its aim is to maintain DC

voltage constant here. The switch is ON current will flow through tat inductor and switch and rotate and inductor will store maximum energy.

**V. EVALUATION OF THE PROPOSED FILTER CONFIGURATION**

It’s an experimental setup so we have taken same rating. We can change the load and we can change input of solar panel. If we change temperature and voltage and also we have given a step change in load then current, DC link voltage and everything will change. If we connect the load of lamp simulation time is 1 then one restriction comes that the load will become reduced on converting. if load are connected with panel that will become 0.5 then load will become decreased and if load is increased then current will also increase In this system when load is increased current is also increased, little bit voltage decreased, power is also increased. Its operation is based on the three conditions shown. Firstly PV array starting with charging mode then giving supply to load and bidirectional converter then remaining power goes to grid whenever load increases. Now second way is only PV array will give the supply to dc load remaining power going to the grid. Third condition both PV battery and grid are giving power and feeding to dc load. Dc load getting power from PV array as well as the grid & the same time charging of battery is also done. Previously no use of battery was there but now battery is used because of PV array completely depends upon the sunlight. Sunlight is not available at evening time so at the morning hour’s power is stored in battery and power is also supplied to load at night time for supplying to dc load.

**VI. RESULTS AND SIMULATION CONDITIONS**

To evaluate the performance of the developed control strategy, the time-domain simulation studies in MATLAB/Simulink environment are presented. The details of the experimental setup are shown in Table IV. In the proposed control MPPT technique is used to generate when turn on and off of IGBT switch. The dc link voltage is to be maintained at constant range for that whenever there is reduction in radiation at the PV array then voltage and current is taken to the MPPT and then turn on time of the switch will get increased and at the same time the current will flow through the inductor and switch only

rotate here itself and then inductor will store maximum energy. Again we get the constant voltage here. So turn on time should be increased to overcome the decreased voltage in dc link. Then that voltage will be stored here and the previous voltage added with the stored voltage then we get the required voltage at dc link and the voltage is step up. The dc source and capacitor is also connected as a dc load. This is a boost chopper and is fed to AC load by an LC filter. And the results are as follow.

TABLE I  
SPECIFICATIONS OF THE EXPERIMENTAL SETUP

Utility	230 V, 50 Hz
PV array	800W @ 1000W/m <sup>2</sup> , 25 <sup>0</sup> c
Boost converter	110 V, 500W
Bidirectional converter	750 VA
DC Load	400 W
Battery	36 V,42 Ah

TABLE II  
SPECIFICATIONS OF THE HYSTERESIS CONTROLLER

Average switching frequency	10KHz
Modulation Index	0.833
Bandwidth Δi	0.1A
DC Link voltage	110V

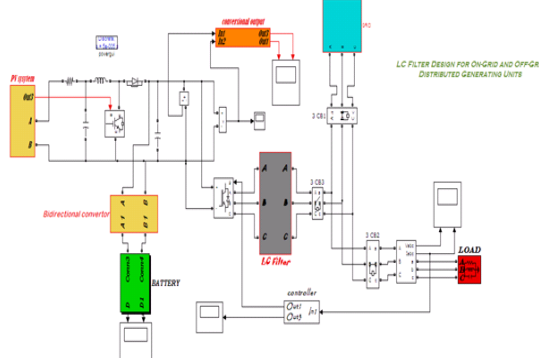


Fig. 8. Simulink Model of Power Flow Management through LC Filter Supplying AC Loads

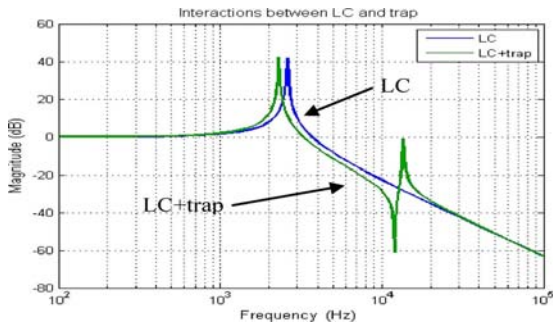


Fig.9. LC transfer function (blue trace) without and (green trace) with trap filter

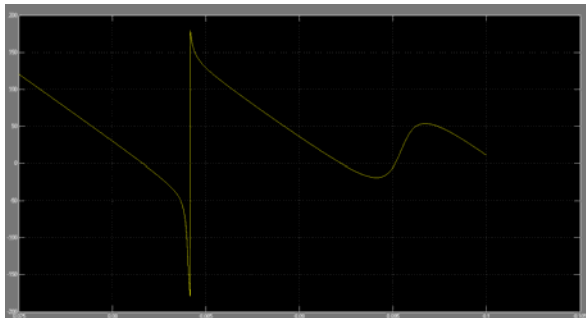


Fig.10. filter output

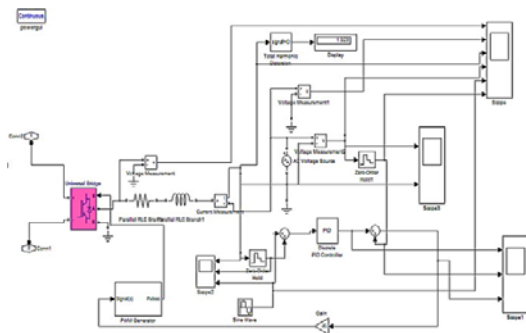


Fig.11. Bidirectional Inverter with Main Grid

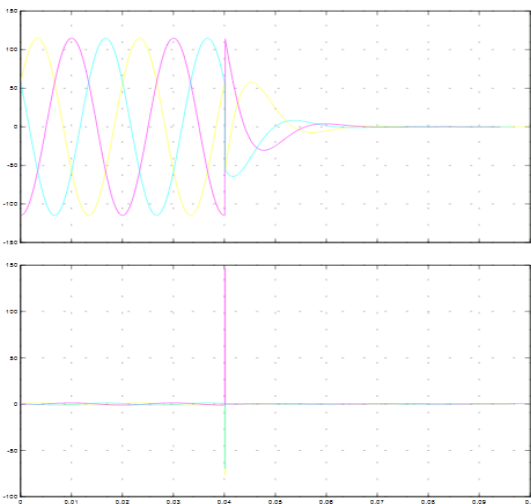


Fig.12. Grid Side Voltages and Currents

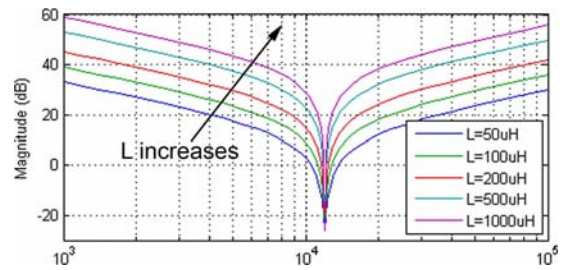


Fig.13. Twelve-kilohertz tuned trap filter impedance Bode diagram with different inductance and capacitance values.

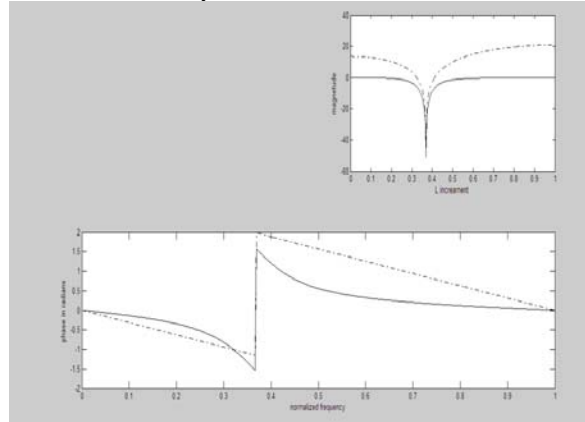


Fig.14. programmable LC output

VII. CONCLUSION

In this paper, the complete filter design procedure for distributed generating units, which are able to operate in both on- and off-grid modes, has been illustrated. Main criteria for sizing each filter section are given and explained. An example design procedure has been performed, in order to demonstrate the accuracy of the proposed criteria. The comparison with the more conventional LCL and LC filter topologies proves a substantial superiority of the performance of the proposed filter configuration. On- and off-grid modes of operation have been also experimentally tested in order to verify filter performances with respect to current and voltage waveforms. Power losses measurements on the proposed prototype have been carried out, too, and they show good agreement with estimated values.

From the simulation result it can be validated that the power management strategy of the designed composite model for a grid connected PV array and battery works for both on-grid as well as off-grid mode of operation maintaining constant DC voltage, achieving desired power sharing between the various sources and DC load with full utilization of PV power. For different modes of operation, the performance of

converter has been observe for both rectifier and inverter modes. The proposed system provides uninterrupted power to dc load by using PV array and grid. A maximum power point tracker is used for obtaining the maximum power from the solar PV module and conversion to the load. A non-isolated DC-DC converter (step up/step down) offers the purpose of conversion maximum power to the load. A DC-DC converter acts as an interface between the load and the module. By varying the ratio of duty cycle the impedance of load as it appears by the source is varied and matched at the peak power point with the source so as to conversion the maximum power. Simulation studies in MATLAB/Simulink environment are presented.

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