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A Study on Components Used In Grid Connected Photo Voltaic Power Generation Systems

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Abstract: *The power produced by solar PV based inverters are having high ripple quantity. And a slow scheme where harmonics are not completely eliminated while grid connection. The paper goes on a brief study on different levels of PV based power generation systems, the inverter types, synchronization schemes used. The operating principles, advantages, dis advantages of each and every method is checked. In a grid feeding type inverter, the voltage magnitudes, the phase sequences, and phase angles of current and voltages are to be checked so that otherwise if there is any change in the parameters, the entire power system will fail or the response at load variation will be very poor. Most of the used methods in converting the DC power generated in PV to AC is using multi-level inverters so that the power generated will be an approximately sine-like wave form. The power is fed to grid is synchronized by using a Phase locked loop (PLL). The PLLs used in power synchronization SOGI-PLL, E-PLL, NTD-PLL, ETD-PLL, MAF-PLL, MHDC-PLL. In most of the cases the power produced is considered as LV type, ie, 230V AC Phase voltage, and low power synchronization devices usually have low rating so that the control will be a bit easy. The device must be able to synchronize power at any type of grid conditions even at grid disturbances. So that a powerful and intelligent synchronization is needed. It's also important that the power generated by inverter must have least amount of harmonics so that it won't affect the ordinary working of a power system. Here usually focused on low voltage residential and offices as the place to install the PV based power generating, because the solar power is available only at day time and in almost every offices the peak demand occurs at day time so it is to be focused.*

Keywords: *harmonics, grid connection, inverters, PLLs, Photo Voltaic cells, grid disturbances, synchronization.*

I. Introduction

Solar power is the superior state of power in all forms where any other type of energy is produced from solar power. Solar energy is one of the purest form of energy which is abundant, free of cost, and easily available. It is better to use solar power directly to the appliances if any sort of conversion mechanism is implemented. Thus, solar energy to electrical energy conversion devices such as Photo Voltaic cells are introduced. Here the photons which fall on a PN junction is directly converted to electrical energy.

In earlier stages, the power produced in PVs are directly utilized in small power applications. It's also important that the power produced in PVs are in DC form and can be used only for that kind of appliances. So the power produced in PV become special case applications or remote area applications. As time passed, the power scarcity increased, and new resources for power is started harvesting. As a part of that the solar power also used for power generation in bulk volume using concentrated solar power dishes and other methods.

After the development of semiconductors and power electronic converters, the power is generated using PV modules in DC form is directly converted to AC using inverters and used. In earlier cases, the PV power based inverters are stand alone and used only to energize a grid isolated load. As the time passed, the excess power produced by the PV inverter can be fed to the grid by some conversion and synchronization mechanisms. So that the grid operates at AC mode where the voltage is mainly a function of sine wave. So that the power produced using PV must be of same parameters. Thus the sine wave inverters are introduced. Where the AC produced in inverters and grid must be in exact same conditions. So that synchronizers are used. To synchronize power produced using power electronic switches, static synchronizers are used. Also to make the inverter wave a sine-like waveform, multi-level inverters are used. So that the inverter will produce an approximate sine-like wave form.

The power produced by the inverter is checked with grid conditions and if both are same, the power generated by PV system is fed to the grid, if the power produced by both are different, the synchronization mechanism will give signals to the controller to make them correct. Usually the voltage, phase sequence and phase angles are checked for synchronization.

The importance is that power produced in the inverters are usually taken as ordinary low voltage of value 110/230V AC. So that the control on the low voltage production will be easy due lo use of low rating applications.

II. Electric Utility

An electric utility is a public or private company usually deals with electrical power production, transmission and distribution. it is also largest power source of a country. Utility is either Government, co-operative or private sector. Now utilities become an open market where the electric power can be generated, sold, or purchased. Utilities now a days are having a problem of increased demand and reduced generation capability. The power flow inside the utility is controlled, regulated and quality check is mainly done by the utility itself. A grid-tied electrical system, also called GTSI where excess power generated can be delivered to grid or if additional load is present, the power can be taken from the grid. Usually the input to the GTSI is from renewable sources (solar, wind, etc.) having a non continuous power source.

III. Solar PV Module

Solar PV modules are used to convert the solar power received from sun to electrical power in DC mode. There are different modes of power production in converting solar power into electrical power so that in earlier cases, concentrated cell solar power systems are used. In which the heating effect of solar energy is used to vaporize a coolant (usually water) and it is circulated in expansion turbines to make electrical power. The working of these systems is as same as steam power plants so that the input is only changed. But the stand by time and starting time of these types of power plants are very low.

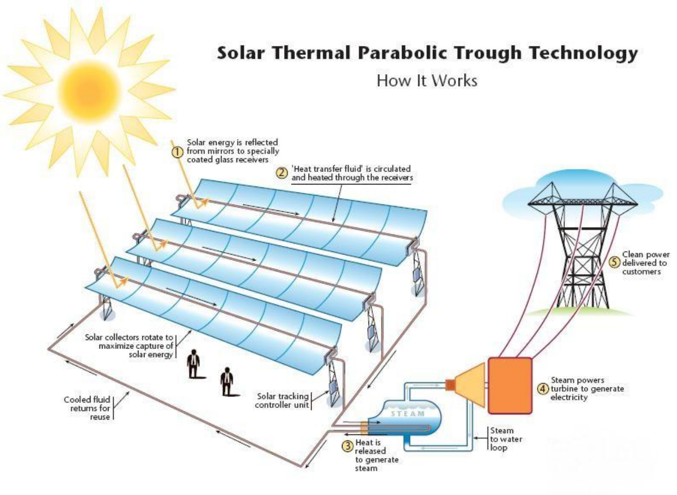

Fig:1 : Parabolic solar trough

Above given is a simple diagram of solar parabolic reflector based thermal power plant. The main problem with it requires much time to start producing power, to start power production it needs to generate massive amount of steam to be produced. It is also a bit problem that the shades caused by clouds also makes the power production to a lower level.

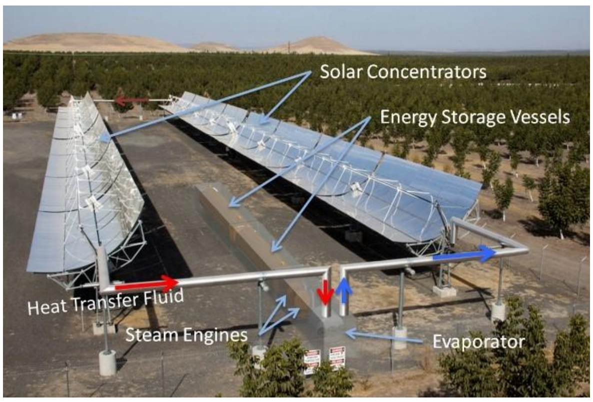

Fig:2 : A solar parabolic reflector

It is also a problem that the size of these type of stations are quite high so that cannot be placed at populated areas. Then the semiconductor oriented Photo Voltaic modules are introduced so that instantaneous power conversion is possible. It also to be noted that the size of this equipment is quite low so that the placing of these becomes so easy.

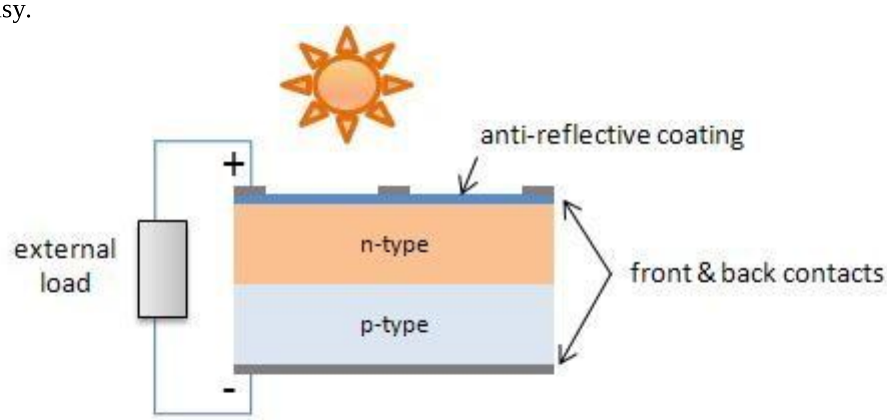

Fig:3 : PV cell sectional view

A PV cell is simply a PN junction diode which is capable of production of electric power when subjected to illumination. When photons are fall on a solar cell the electron-hole pairs isolate and passes through the anode and cathode. These anodes and cathodes can be connected to external leads to connect load.

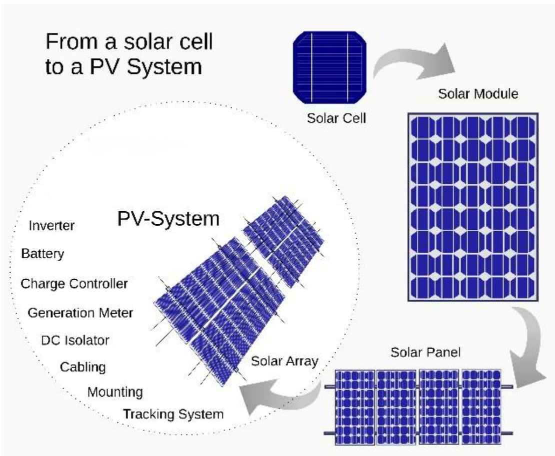

Fig:4 : Solar cell combinations

Solar cells can be connected in series or parallel combinations to meet the current or voltage measures. Usually the voltage output of each cells are 2V and the total module output will be multiples of 2. Several modules are combined to form solar panels and several panels are combined to form a solar power station. The power produced in solar power station will be in DC form and is to be converted to AC by means of an inverter.

	Monocrystaline Panels	Polycrystaline Panels	Thin Film Panels
Type			
Efficiency	14% – 18% cell efficiency	12% – 14% cell efficiency	5% – 6% cell efficiency
Temperature Tolerance	0% +5%	-5% +5%	-3% +3%
Life Time	25-30 year life span	20-25 year life span	15-20 year life span
Durability	Hail resistant 25 year P & M	25 year P & M warranty	25 year P & M warranty

Fig: 5 : Comparison of panels

Usually used solar panels are of 3 types: monocrystalline, polycrystalline, and thin film. The most efficient one is monocrystalline but the manufacturing process for monocrystalline makes it so costly.

IV. MPPT

MPPT or Maximum Power Point Tracking is a technology used to extract maximum power from a variable generating station. The voltage provided by the output of MPPT will be having maximum power harvested from the source. Here the maximum power generated by the PV cell depends on weather conditions and day or night.

MPPT can be used for the following conditions:

- In cold weather or cloudy climate.
- Battery source is present and having low charge.

A MPPT uses an algorithm where it is capable of generating maximum output current with rated voltage.

MPPT is applied on a DC-DC converter which is capable of generating stiff voltage and maximum current. usually connected to a fixed voltage DC line where multiple sources are connected.

Examples of DC to DC converter are

- **Boost converter** having output voltage greater than input voltage.
- **Buck converter** having output voltage less than input voltage.

Main features of MPPT solar charge controller:

- Usually used to generate power from PV module and coupled to solar power controller in stand alone systems.
- MPPT solar power controller is driven by either Buck or Boost converter and given to the inverter input along with a capacitor filter to remove ripples generated by the converter part.
- MPPT helps to generate usual charging voltages of 24V, 48V etc. from a variable input source for DC applications including inverter.
- MPPT helps in reducing complexity and there by increased power harvesting capability.
- Can be used not only in solar but also in any power source (solar, wind, small hydro etc.) to harvest more power from the available one.

V. Multi Level Inverter

The inverters used usually are multi-level inverters so that the power produced will be a sine like wave form. Usually 7 or 11 level multi-level inverters are used to get low THD valued sine wave outputs. But the main problem with this method is the production of switching scheme generation. For a multi-level inverter, there will be a pulse train oriented switching so that the switching losses in each switch sum up to get a large value of loss inside the switch also there will be power loss in terms of on time of the switches. So the net efficiency of the system will be a bit low.

But here the efficiency is least concentrated because we are not paying for the input energy. Only conversion and feeding back mains is the costly problems.

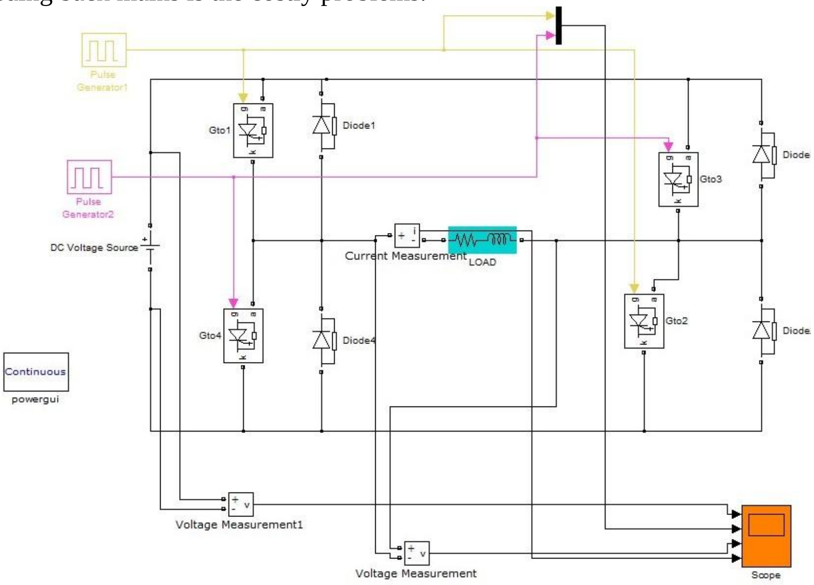

fig:6 : Simple Inverter

A simple inverter is a H-bridge type where 4 switches are used and each operates at frequency of utility. But the above mentioned one is a single step type and is not a grid connected inverter the out pot of inverter is AC type but even if it's not sine wave.

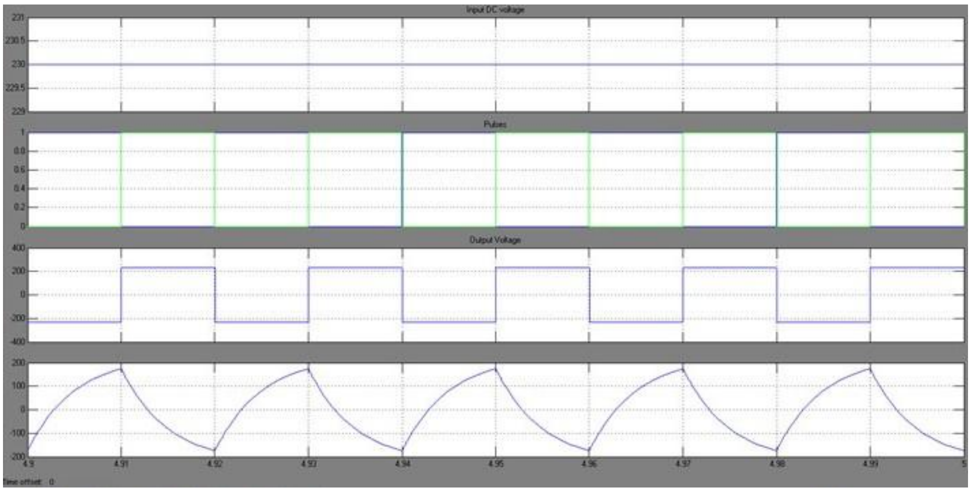

Fig:7 : Simulink scope output waveforms

The scope output waveforms itself shows that they are not a sine wave. This also shows that the power produced by a simple inverter cannot be directly connected to electrical appliances so that the change in input waveform may cause damages in inner circuitry of devices. (Usually, motors, inductive devices and capacitive devices perform different from the usual performance). Then the introduction of multilevel inverters which uses almost same functioning of a simple H-bridge type where multiple H bridges are used as combinations.

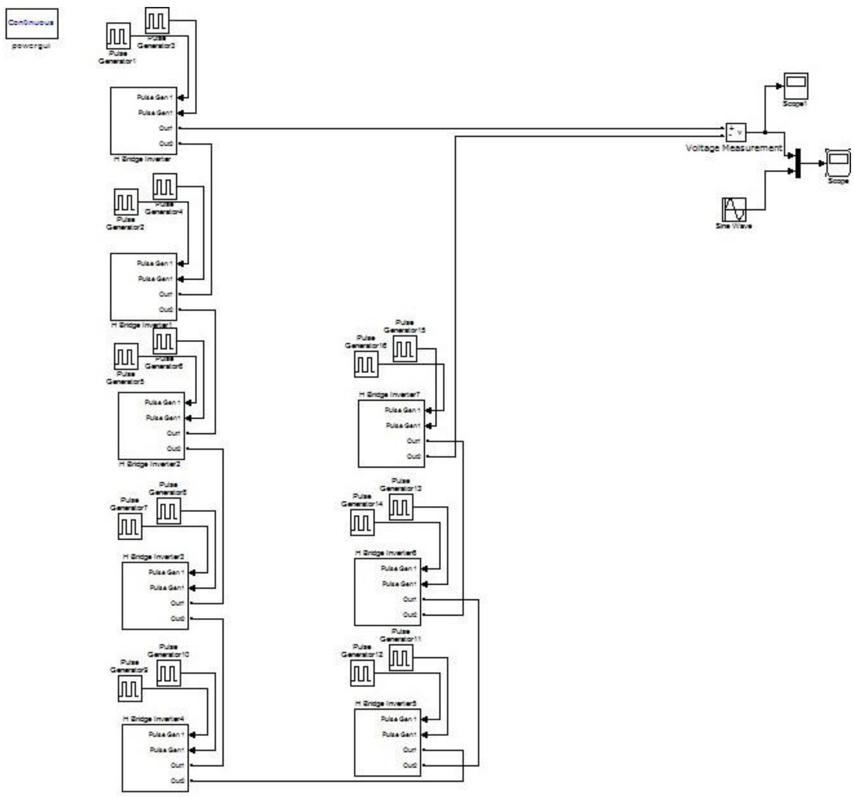

Fig:8 : Multi-level inverter.

In an each single switching block of a multi-level inverter the inner circuitry is H bridge type where each operates at same frequency but different duty period so that the power generated will be a sine like one.

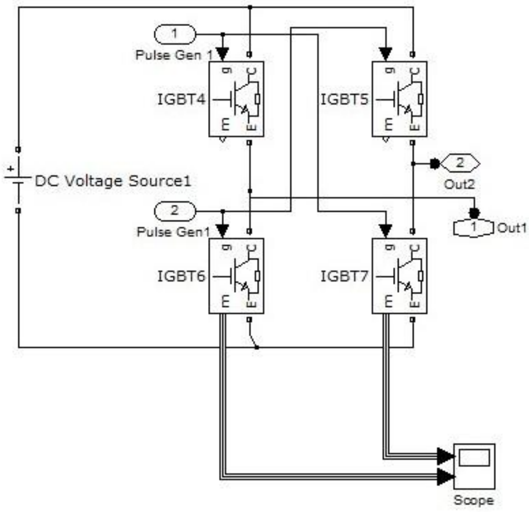

Fig:9 : Inner circuitry on switching modules.

Usually used switches are either IGBTs or SCRs as per the requirements.

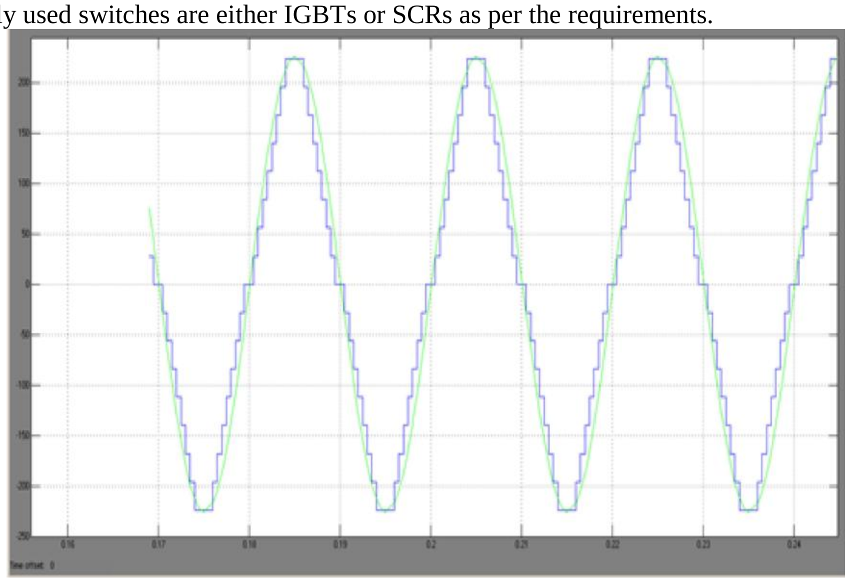

Fig:10 : Simulation output.

The studies related to multi-level inverters says that taking average value of output will give the character of produced wave. If the levels of inverter is increased, the sine component of the output wave form is increased. But the problem is of the complexity of circuit. More number of switching components need to be designed, the controller programming goes on difficult. Here a 9 level inverter is used. Means the switch has 9 levels of outputs.

VI. Synchronization

A grid connected solar power generating station needs to be always be alert so that the grid disturbances and it needs to isolate when the grid fails. If it won't isolate, the power supplied by the solar will energize the grid and the solar plant become over loaded and cause injuries to the components inside the converters and other parts. It's also important that once the grid is isolated, if there may be any work on power system network going on the solar power will be still feeding power. So if any worker is trying to enter the grid may get electrical shock and other hazards also cause problems. So Synchronizer not only need to synchronize, but also it needs to check the islanding modes of a power system. A solar powered unit can be installed everywhere in this paper its dealing with ordinary Low voltage application. So that the control and isolation will be easy.

Even if the grid is isolated, the user have to be powered that the local loads need continuity and isolation mode helps for that. So that the utility gets isolated and the user will not affect the continuity of the supply. Here usually used Synchronization scheme is PLL (Phase Locked Loop) based. Ie, a PLL based device keeps on working dedicatedly for the synchronization and isolation of the local grid (say mini solar power plant installed by residential customers and offices).

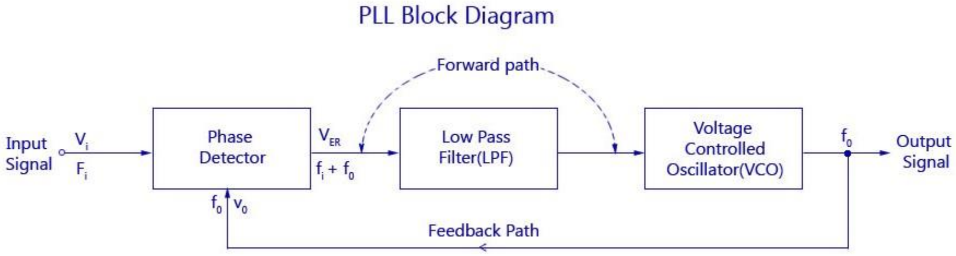

Fig:11 : Basic PLL.

Phase locked loops (PLL) with all ac/dc converters take an important role in providing a reference phase signal synchronized with the ac system. This reference signal is used as a basic carrier wave for deriving valve-firing pulses in control circuits. The actual valve-firing instants are calculated using the PLL output as the base signal and adding the desired valve firings. Typically, the desired firings are calculated in the main control circuit achieving regulation of some output system variables. The dynamically changing reference from a PLL therefore influences actual firings and it plays an important role in the system dynamic performance.

The input signal V_i with an input frequency fi is passed through a phase detector. A phase detector basically a comparator which compares the input frequency fi with the feedback frequency f_o. The phase detector provides an output error voltage V_{er} =(f_i+f_o), which is a DC voltage. This DC voltage is then passed on to an LPF. The LPF removes the high frequency noise and produces a steady DC level, V_f=(F_i-F_o). V_f also represents the dynamic characteristics of the PLL.

The DC level is then passed on to a VCO. The output frequency of the VCO (f_o) is directly proportional to the input signal. Both the input frequency and output frequency are compared and adjusted through feedback loops until the output frequency equals the input frequency. Thus the PLL works in these stages – free-running, capture and phase lock.

Once the phase is locked, the PLL goes on checking Frequency values. If the frequency is suddenly dropped to enormous value along with voltage, that means a grid failure. So the breaker isolates the PV power generation plant from grid and goes to islanding mode. It again monitors the grid voltages. Once the grid become live, it sends the signals to the controller and again the inverter output is re-designed and synchronized to grid.

Some standard PLL are given below:-

- SOGI - PLL (Second Order Generalized Integrator - PLL)
- E - PLL (Enhanced - PLL)
- NTD - PLL (Non frequency dependent Transfer Delay - PLL)
- ETD - PLL (Enhanced Transfer Delay - PLL)
- MAF - PLL (Moving Average Filter - PLL)
- MHDC - PLL (Multi Harmonic Decoupling Cell - PLL)

A. SOGI - PLL (Second Order Generalized Integrator - PLL)

In order to obtain a balanced set of in-quadrature outputs with correct amplitudes, the center frequency of the SOGI structure must be equal to the input signal frequency. To achieve this goal, the center frequency is adjusted by an estimation of the grid voltage frequency. The estimated frequency is obtained by using a synchronous reference frame PLL (SRF-PLL).

Input signals of the SRF-PLL will result in a very poor dynamic response in estimation of the grid voltage frequency, and may degrade the stability of the PLL. This deduction is true when a PI compensator is used as the loop filter in the SRF-PLL.While, in the suggested structure, a PI-lead controller is employed as the loop filter. Using a detailed mathematical analysis, it will be shown that, how adding a lead compensator to the conventional PI controller significantly improves the dynamic response and the stability margin of the SRF-PLL.

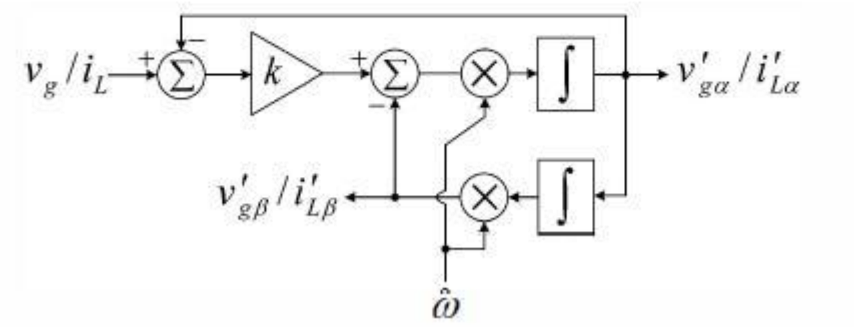

Fig:12 : SOGI-PLL.

However, a very low value of k degrades the dynamic performance of the SOGI, resulting in a significant delay in extraction of the reference compensating current. It is well known that, during the load transients, the delay in extraction of the reference current increases the duration for which APF must sink/source the fundamental current, hence increases the required APF rating. Therefore, it is necessary to find a satisfactory compromise between the speed of response and the harmonic rejection.

From the harmonic rejection point of view, the selected value for the damping factor is adequate for low distorted load currents. However, in cases, where the load current have a high harmonic content it may not be adequate.

Low response higher order harmonics due to second order component. Is the leading problem of these kind of PLLs.

B. E - PLL (Enhanced - PLL)

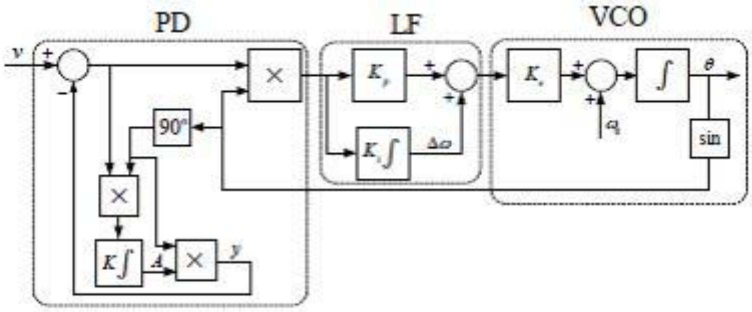

Fig:13 : E-PLL.

Enhanced phase-locked loop (EPLL) is a frequency-adaptive nonlinear synchronization approach. Its major improvement over the conventional PLL lies in the PD mechanism which allows more flexibility and provides more information such as amplitude and phase angle. There are three independent internal parameters K, K_pK_v and K_iK_v . Parameter K dominantly controls the speed of the amplitude convergence. K_pK_v and K_iK_v control the rates of phase and frequency convergence.

EPLL can provide higher degree of immunity and insensitivity to noise, harmonics and unbalance of the input signal. It is an effective method for synchronization of the grid-interfaced converters in polluted and variable frequency environments. In addition, EPLL can provide the 90 degrees shift of the input signal. Therefore, it is an attractive solution in some single phase system applications.

Low adaptive filtering and dynamic response is the main drawback of this type of PLL.

C. NTD - PLL (Non frequency dependent Transfer Delay - PLL)

In recent years, many approaches to generate the orthogonal signal have been proposed, the simplest perhaps being the transfer delay-based method. In the transfer delay-based PLL (TD-PLL), the orthogonal signal is generated by delaying the original single-phase signal by T/4 (one-quarter of a period).

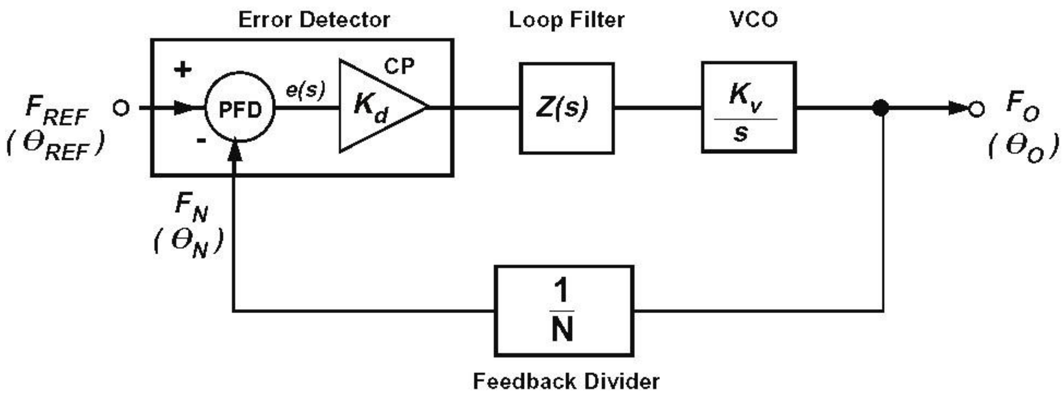

Fig:14 : NTD-PLL.

The phase shift caused by the transfer delay block, however, will not be exactly 90degree under off-nominal grid frequencies, which results in errors in the estimated quantities by the TD-PLL. To alleviate this issue, an improved version of TD-PLL, called the non-frequency dependent TD-PLL (NTD-PLL), has recently been proposed. The NTD-PLL uses another T/4 delay unit in its feedback path to make the PLL immune to grid frequency variations.

D. ETD - PLL (Enhanced Transfer Delay - PLL)

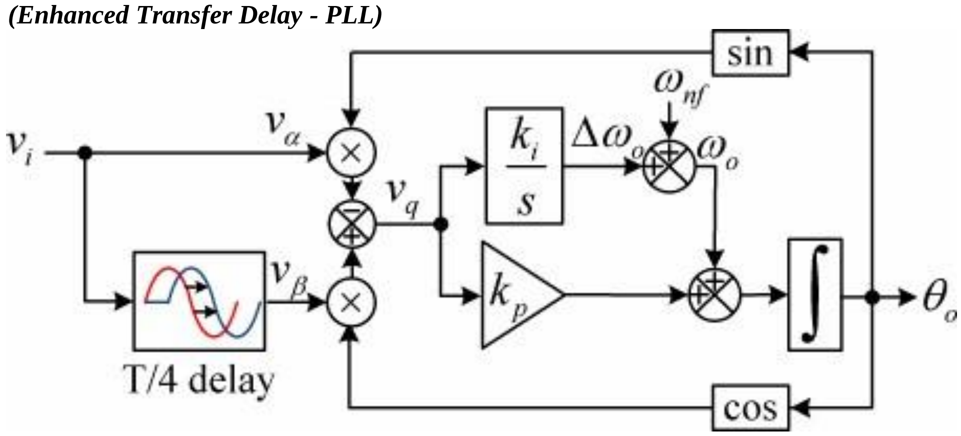

Fig:15 : ETD-PLL.

PLLs align the rising edge of the reference input to a feedback using the phase-frequency detector (PFD). The falling edges are determined by duty-cycle specifications. The PFD produces an up or down signal that determines whether the VCO needs to operate at a higher or lower frequency. PFD output is applied to the charge pump and loop filter, which produces a control voltage for setting the VCO frequency. If the PFD produces an up signal, the VCO frequency increases; a down signal decreases the VCO frequency.

The PFD outputs these up and down signals to a charge pump. If the charge pump receives an up signal, current is driven into the loop filter. Conversely, if the charge pump receives a down signal, current is drawn from the loop filter. The loop filter converts these up and down signals to a voltage that is used to bias the VCO. The loop filter also removes glitches from the charge pump and prevents voltage over-shoot, which filters the jitter on the VCO. The voltage from the loop filter determines how fast the VCO operates. The VCO is implemented as a four-stage differential ring oscillator. A divide counter (m) is inserted in the feedback loop to increase the VCO frequency above the input reference frequency. VCO frequency (f_{VCO}) is equal to (m) times the input reference clock (f_{REF}). The input reference clock (f_{REF}) to the PFD is equal to the input clock (f_{IN}) divided by the pre-scale counter (n). Therefore, the feedback clock (f_{FB}) applied to one input of the PFD is locked to the f_{REF} that is applied to the other input of the PFD.
The VCO output can feed up to six post-scale counters C_0, C_1, C_2, C_3, C_4, and C_5). These post-scale counters allow a number of harmonically related frequencies to be produced within the PLL.
Lower order harmonics is the main problem of these types of PLLs.

E. MAF - PLL (Moving Average Filter - PLL)

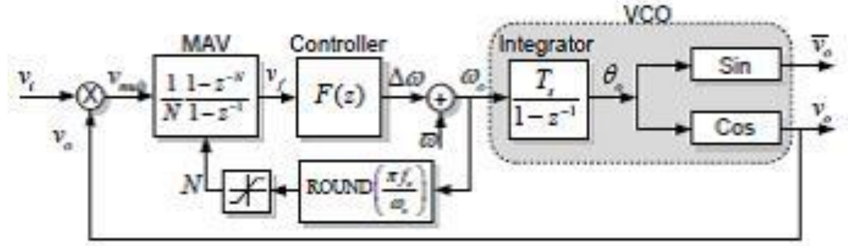

fig:16 : MAF-PLL.

For real applications, the grid frequency f_1 can vary in a limited range $f_1 \pm\Delta f$ defined by the corresponding standards. To achieve the appropriate attenuation of the signal n for v_i with variable frequency, two conditions must be provided:

1) Equation $N= f_s/(2f_1)$ should be satisfied.
2) N should be an integer value.

There are two possible solutions:

i. The online variation of window size N with fixed sampling frequency f_s and\\
ii. The variation of the sampling frequency fs with constant window size N.

Low response even-though it have improved harmonic reduction is the main dis advantage of these type of PLLs.

F. MHDC - PLL (Multi Harmonic Decoupling Cell - PLL)

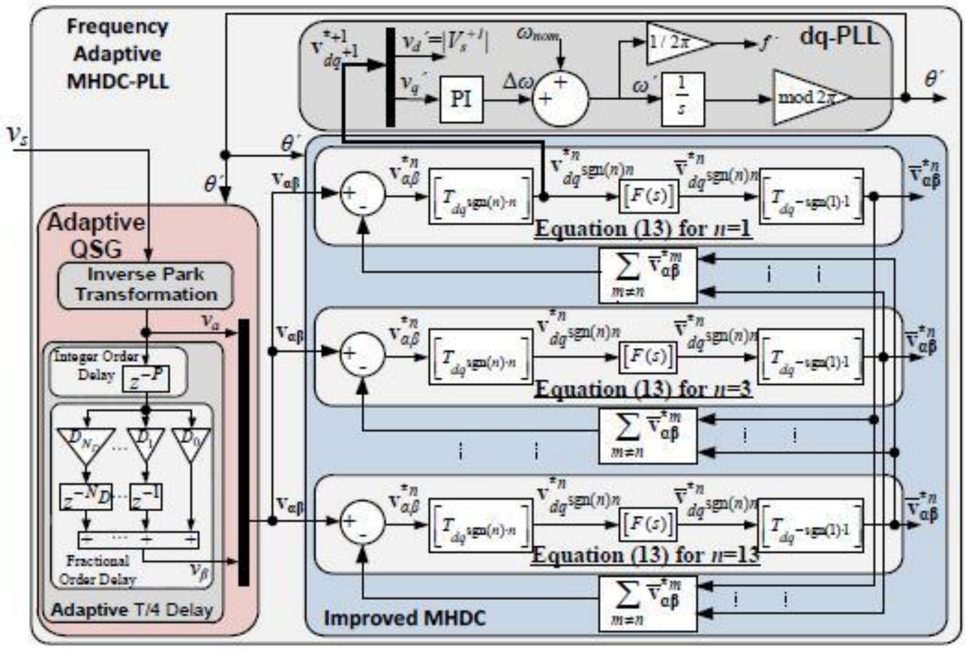

Fig:17 : MHDC - PLL (Multi Harmonic Decoupling Cell - PLL).

The MHDC-PLL proposed to employs a QSG unit to generate the in-quadrature voltage vector ($V_{\alpha\beta}$) that is free of high-order harmonics, the MHDC to dynamically decouple the effect of low-order harmonics, and the dq -PLL algorithm to estimate the phase angle of the fundamental voltage component (V_+). The MHDC-PLL suffers from the increased implementation complexity of the MHDC and the non-ideal or unsatisfactory responses of the QSG under frequency changes as it has been observed.

Hence, the following propose schemes to address these issues. The QSG of the MHDC-PLL is based on a combination of an IPT structure to cancel out the high-order harmonics and a T/4 delay unit, where T is the nominal period of the grid voltage, to generate the in-quadrature voltage vector (i.e., $V_{\alpha\beta}$). The IPT method is based on a forward Park's transformation, on a low-pass filter ω $f_1/(s+\omega f_1)$, and on a backward Park's transformation as described. It should be noted that the IPT method is not used for the in-quadrature vector $V_{\alpha\beta}$ generation, since the filtering effect of IPT on V_α and V_β is different. Thus, a more complicated design of the

MHDC is required for cancelling out the low-order harmonics. Here, the IPT is only used for filtering the high-order harmonics of the grid voltage Vs. Therefore, the voltage Va is free of high-order harmonics and then a T/4 delay unit is used for generating the in-quadrature voltage vector $V_{\alpha\beta}$

- Proposed frequency adaptive method overcomes the inaccuracies under non-nominal frequency caused by the initial QSG and thus, an accurate operation can be achieved under any grid frequency.
- For a proper design of the improved MHDC, it is first necessary to define the number of harmonic-orders that are considered and eliminated by the decoupling network.
- The effect of the higher order harmonics is minimized due to the second-order band-pass filtering.
- The proposed frequency adaptive MHDC-PLL can achieve a fast and accurate response under any harmonic distortion and under any grid faults and the required processing time of the proposed synchronization algorithm is significantly less.

Fast and accurate performance in harmonic distortion and grid disturbances is the main feature of these type of PLLs.

VII. Figures And Tables

VIII. Conclusion

By studying through the paper the data of pre- published papers are useful that each and every part is important. For a grid connected PV generation system each and every part is to be monitored. The study is mainly focused on Inverting section and different PLLs used in the synchronization scheme. In most of the grid tied inverters the power produced must be in sine wave form where achieving it completely is difficult using semiconductor switches. But while using multi-level inverters the power produced can be approximated to sine wave form. So when levels of an inverter is increased, the output of the inverter will became sine wave type. The problem with this scheme is of increased complexity and switching losses.

While going through grid connection part, it is done through using Phase Locked Loops (PLLs) where different grid conditions to be checked and the power generated by the PV is connected to grid. Each and every conditions of grid is continusly monitored by the synchronization part and islanding modes are operated.
Different methods used for grid interfacing using PLL are following and their features.

- SOGI- PLL (Second Order Generalized Integrator – PLL)
  Low response higher order harmonics due to second order component.
- E- PLL (Enhanced – PLL)
  Low adaptive filtering and dynamic response.
- NTD – PLL (Non frequency dependent Transfer Delay – PLL)
  Cannot completely eliminate reading inaccuracies caused by harmonics.
- ETD – PLL (Enhanced Transfer Delay – PLL)
  Lower order harmonics affects the power quality.
- MAF – PLL (Moving Average Filter – PLL)
  Low response even-though it have improved harmonic reduction
- MHDC-PLL (Multi Harmonic Decoupling Cell – PLL)

Frequency adaptive MHDC-PLL
Fast and accurate performance in harmonic distortion and grid disturbances.

By going through each and every PLL logics it's clear that most of them have problems either due to higher harmonics or at lower harmonics. So a better PLL is to be designed that which has lesser effect on harmonics and must be capable of synchronization even at grid disturbances.

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