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αβ To Dq (Parke's) Transform Based Control Study On Grid Tied Iverter To Operate As A FACTS Device For Improving Power Transfer Through Transmission Lines

Madhavadas M[1], Vibin C Thomas[2]
[1](PG Scholar, Adi Shankara Institute of Engineering and Technology, Kalady, India)
[2](Asst. Professor, Adi Shankara Institute of Engineering and Technology, Kalady, India)

Abstract: *The power produced by the solar inverter can be linked to grid either in 3 phase or in single phase mode. For low power applications the produced power is linked to grid by single phase power conversion techniques. Most of the power converters work on different conversion techniques at PV-DC side and Inverter-AC side. Here the introduced technique provides both DC and AC sides which are controlled simultaneously (Single stage conversion). The major advantage is that the control provides better time management in isolating and grid tie time requirement. Here a SRF PLL is used, and controlled by Parke's transformation for the AC side, and Fractional Open Circuit Voltage (FOCV) based MPPT control for the DC side is provided. The VSI can be controlled by Hysteresis control mode implemented as an internal loop where the reference current magnitude for this loop is generated from an external Voltage control mode. An LC filter can be designed for wave shaping of the inverter output power. The same can be operated as a STATCOM mode with DC bus powering from solar PV modules.Basically a STATCOM works as DVR mode to regulate the voltage level of a line there by keeping the power factor of the line in a safest limit of power transfer. It can be achieved by the same parke's transformation oriented control.*
Keywords: *GTSI, STATCOM, isolator, SRF PLL, FOCV, Hysteresis control, THD.*

I. Introduction

The power produced from PV cells are of DC form and are utilized as direct form on DC loads and for AC loads the power is converted to AC form by use of an inverter. For a normal inverter most of them works on voltage source model with PWM controlled switching. And most of the inverters are used with support of batteries. Those batteries are either powered by charging directly from available utility supply or by other means (Solar etc.).

The proposed design works as a master slave model for the control on DC-DC conversion and DC-AC conversion. The PV voltage is compared with a reference value voltage usually set above grid voltage.[1] and the error signal is passed to a PI controller which generates a magnitude of error which can be used as magnitude of reference current for Hysteresis current control. The current wave generated will be in phase with grid voltage and obviously the voltage also. The frequency of the whole system is always monitored and a control mechanism is provided to isolate the whole system from grid under low or high frequencies. The frequency regulation limit is kept +3% and -3%. The regulation is also provided to voltage that the voltage at Point of Common Coupling (PCC) is not varied at any manner so that there is no distortion in grid voltage at all[6].

1.1. Photo Voltaic convertors

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.

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.

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.

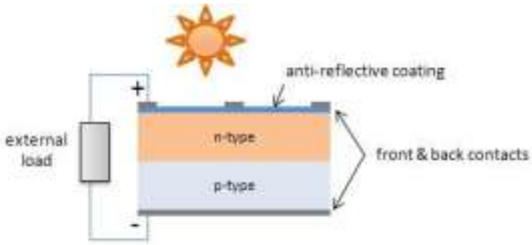

Fig. 1. PV cell sectional view

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.

1.2. Single-phase Voltage Source Inverters

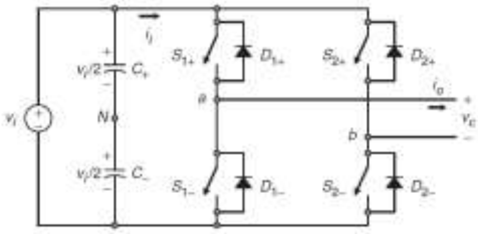

Fig. 2. Full Bridge VSI

This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, both switches S1+ and S1− (or S2+ and S2−) cannot be on simultaneously because a short circuit across the dc link voltage source vi would be produced. Undefined ac output voltage condition, the modulating technique should ensure that either the top or the bottom switch of each leg is on at any instant. It can be observed that the ac output voltage can take values up to the dc link value vi,which is twice that obtained with half-bridge VSI topologies[7].

Several modulating techniques have been developed that are applicable to full-bridge VSIs. Among them are the PWM (bipolar and unipolar) techniques.

1.3. 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.

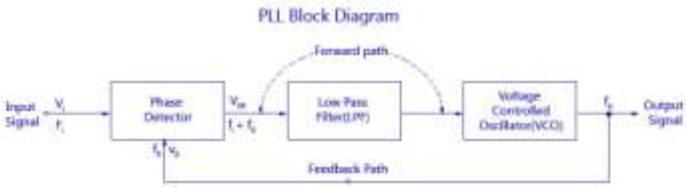

Fig. 3. Basic PLL

The input signal Vi 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 fo. The phase detector provides an output error voltage

Ver =(fi+fo),

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,

Vf=(Fi-Fo).

Vf also represents the dynamic characteristics of the PLL.

1.4. Statcom

Basically it is a Flexible AC Transmission equipment which helps to improve the power transmitted through power lines.DC to AC or AC to AC converters are operated as voltage and current sources and they produce reactive power essentially without reactive energy storage components by circulating alternating current among the phases of the ac system. Functionally, from the standpoint of reactive power generation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control. Like the mechanically powered machine, they can also exchange real power with the ac system if supplied from an appropriate, usually dc energy source. Because of these similarities with a rotating synchronous generator, they are termed Static Synchronous Generators (SSGs).[3] when an SSG is operated without an energy source, and with appropriate controls to function as a shunt-connected reactive compensator, it is termed, analogously to the rotating synchronous compensator (condenser), a Static Synchronous Compensator (Condenser) or STATCOM or(STATCON).

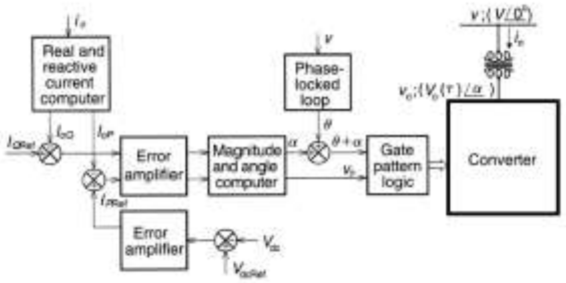

Fig. 4. Direct control method for of STATCOM

By varying the amplitude of the output voltages produced, the reactive power exchange between the converter and the ac system can be controlled in a manner similar to that of the rotating synchronous machine. That is, if the amplitude of the output voltage is increased above that of the ac system voltage, then the current flows through the tie reactance from the converter to the ac system, and the converter generates reactive (capacitive) power for the ac system. If the amplitude of the output voltage is decreased below that of the ac system, then the reactive current flows from the ac system to the converter, and the converter absorbs reactive (inductive) power. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero[3].

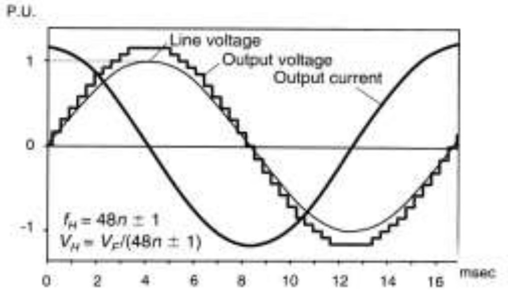

Fig. 5. Output waveforms of STATCOM

input signals are again the bus voltage, u, the converter output current, io, and the reactive current reference, $Iqref, plus the dc voltage reference Vdc. This dc voltage reference determines the real power the converter must absorb from the ac system in order to supply its internal losses. As the block diagram illustrates, the converter output current is decomposed into reactive and real current components. These components are compared to the external reactive current reference (determined from compensation requirements) and the internal real current reference derived from the dc voltage regulation loop. After suitable amplification, the real and reactive current error signals are converted into the magnitude and angle of the wanted converter output voltage, from which the appropriate gate drive signals, in proper relationship with the phase locked loop provided phase reference, are derived. Note. That this internal control scheme could operate the converter with a dc power supply or energy storage as a static synchronous generator. In this case the internal real current reference would be summed to an externally provided real current reference that would indicate the desired real power exchange (either positive or negative) with the ac system. The combined internal and external real current references (for converter losses and active power compensation), together with the prevailing reactive current demand, would determine the magnitude and angle of the output voltage generated, and thus the real and reactive power exchanged with the ac system[3].

II. New Topology

Here a new control methodology is being introduced for the control of a Grid Tied Solar Inverter(GTSI). On through the literature survey the control part of the existing topologies are studied and some part are simulated as for reference. The power from solar is utilized here because the other forms conversion(Wind, tidal, etc.) results in loss of power. The power from sun is the basic reason for the existence of life in earth. The grid tie solar conversion systems doesn't use any power storage devices and hence the cost of installation is very low. It also allows power import or export from the utility grid as by the variation in auxiliary load variations and hence makes it flexible to real time variation of power usage.

Fig. 6. Block Diagram

The proposed technology uses a better control over Single Phase Grit Tied inverter with better control over frequency controlled isolation on grid disturbances. The control and reference sine wave generation was the crucial task for the control of a grid tied inverter. and that can be reduced by using transformation methods available. For the control of a 3-phase inverter mostly used one is the clarke's transformation. which is the conversion of available rotating frame to corresponding static frame ie, abc to dq frame. And the control for the 1-phase inverter can be done by using Parke's transformation where the αβ frame is transformed to dq for the control purposes. The required □ □ by phase shifting the available single phase voltage by 90˚.

Here the power produced by PV which is in the form of DC is converted to Grid synchronized AC with respect to a proposed control topology.

Here a two loop oriented control is given in which one is the outer loop where voltage control is given and the error value produced by the voltage is used to generate the magnitude of the current to be injected. The current is then controlled to attain the best Maximum power point for the available DC power from the PV panel.

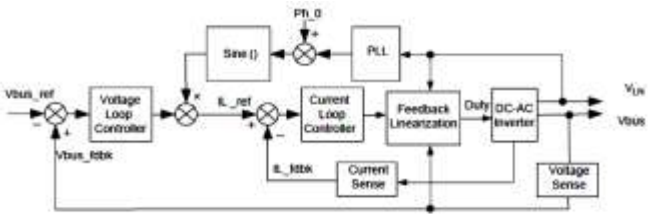

Fig. 7. Block Diagram of Inverter control

$$I_\alpha = \frac{2}{3} I_a - \frac{1}{3}(I_b - I_c)$$

$$I_\beta = \frac{2}{\sqrt{3}}(I_b - I_c)$$

For the better control, the Parke's transformed voltage and DC available voltages are compared to make the error value such that the open circuit voltage at Point of common coupling (PCC) should be greater than the grid voltage. And the error voltage is passed through a PI controller where tuned to attain minimum error in very short time and the magnitude produced by the controller can be taken as a magnitude for the reference current for the control of inverter.

The inverter is controlled using current controlled mode such that the terminal current and input reference are always checked and switches are operated to oscillate the output current in between threshold values of reference.

The overall process is said to be working at strict grid frequency of utility. Any variation from grid frequency say a 3% variation the immediate terminal control actuates and the whole system is isolated from the grid. The control is a part of grid availability identification and in almost every available designs frequency oriented control on islanding is given.

2.1. Inverter control

The Shown is the Hysteresis controlled gate pulse generator for inverter. Here three inputs are given to the controller. The Feedback current at port 1, Reference current at port 2 and breaker condition.

The Reference signal is compared with zero.If it is above zero one of the switch in Positive half is turned on (say the gate 1) and the reference is compared with feedback so that the feedback must be within the threshold limit of the set relay value and according to the value of feedback current the switch which is in pair operation with gate 1 (say gate 4) is switched. Which means the upper limb is made on and modulated switching pulses is given to the lower switch. This is done to reduce the switching losses when two switches are simultaneously operated. This whole precces is for the positive half cycle. For negative half cycle, the zero level comparation is done and if the reference current is below one of the negative switch is turned on (say gate 2) and the reference-feedback control and the threshold limit based switching is given to the pair switch (say gate 3). And thus a complete sine wave is formed.

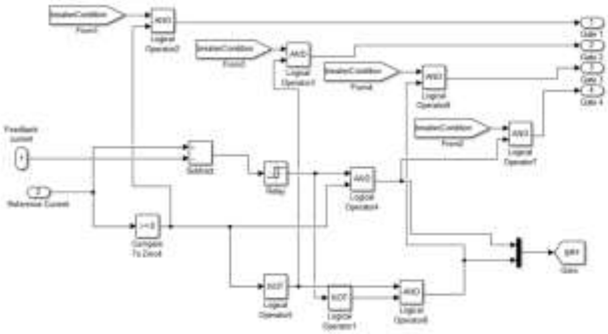

Fig. 8. Hysteresis current controller

2.2. Transformation and PLL

The transformation and PLL gives the grid interaction of our inverter. The grid voltage is passed through a PLL so that the PLL outputs the frequency and angle of rotation of input wave. The same input voltage wave is used to generate static dq frame the inputs to the Parke's transformation is one in phase sine wave and a 90^o phase shifted wave form. Actually it uses 3 inputs but the third input is zero itself and ignore that.

2.3. Grid Equivalent

The system of a GTSI requires a Grid reference model and the SMIB is a usually used method for grid oriented studies. For a large power system it is said to have high number of power system components such as Generators, Transmission lines, breakers, etc. So for small disturbances and all cases the grid frequency and voltage is said to be constant.

The SMIB is said to be an AC voltage source in series with a low value inductor.

2.4. Grid isolation control

Grid frequency controller have implemented to isolate the entire system from grid at frequency variations. A regulation of +3\% and -3\% is given to the controller.

The breaker will keep connected only of the grid voltage is within the regulated limit of utility frequency. any failure to that condition leads to breaker operation and the system gets isolated from the grid.

2.5. LC Filter

The function of an LC filter is wave shaping. The output of an inverter will be of a bi directional pulse train which may not have a sinusoidal shape.As a result the Harmonic distortion of fundamental can be reduced.

III. STATCOM HYBRID MODEL

A novel voltage control together with auxiliary damping control for a grid connected PV solar farm inverter to act as a STATCOM both for increasing transient stability and consequently the power transmission limit. This technology of utilizing a PV solar farm as a STATCOM is termed PV-STATCOM. Similar STATCOM control functionality can also be implemented in inverter for improving the transient stability of the system. One SMIB system uses only a single PV solar farm as PV-STATCOM connected at the midpoint whereas the other system uses a combination of a PV-STATCOM and another PV-STATCOM or an inverter based wind Distributed Generator (DG) with similar STATCOM functionality[1].

The switching signals for the inverter switching are generated through two current control loops in d-q-0 co-ordinate system. The inverter operates in conventional controller mode only provided that Switch-2 is in OFF position. Vd=0 hence, Qref is only proportional to Id which sets the reference Idref for the upper control loop involving PI1. Meanwhile, the quadrature axis component Iq is used for DC link voltage control through two PI controllers (PI-2 and PI-3) according to the set point voltage provided by the MPPT and as well as injects all the available real power P to the network. To generate the proper IGBT switching signals, the d-q components (md and mq) of the modulating signal are converted into three phase sinusoidal modulating signals and compared with a high frequency (5 kHz) fixed magnitude triangular wave or carrier signal.

In the PCC voltage control mode of operation, the PCC voltage is controlled through reactive power exchange between the DG inverter and the grid. The conventional Q control channel is replaced by the PCC voltage controller, simply by switching the Switch-1 to the position A. The rest of the controller remains unchanged. The upper current control loop regulate the PCC voltage where the lower current control loop is used for DC voltage control. The amount of reactive power flow from the inverter to the grid depends on set point voltage at PCC. The parameters of the PCC voltage controller are tuned by systematic trial and error method to achieve the fastest step response, least settling time and a maximum overshoot of 10-15%[1][2].

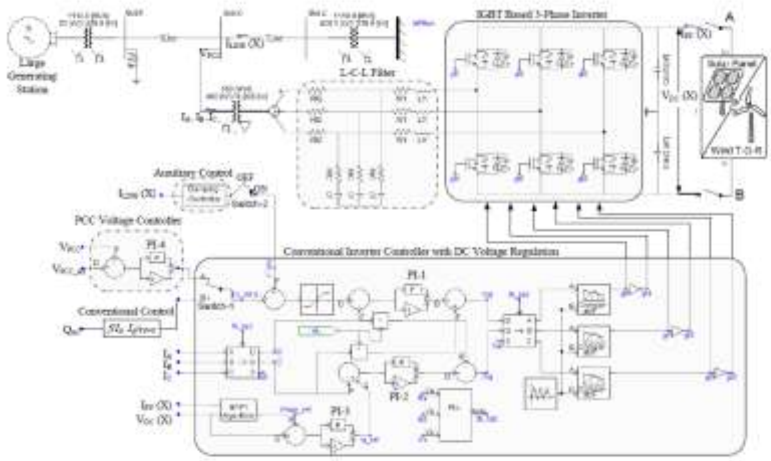

Fig. 1. PV STATCOM [1]

The damping controller is activated by toggling Switch-2 to the ON position. This damping controller can operate in conjunction with either the conventional reactive power control mode or with the PCC voltage control mode by toggling the Switch-1 to position B or A, respectively[1].

IV. Conclusion

A new control method for single phase grid tied solar inverter can be designed and simulated. As a result faster control is possible. An LC combination filter is designed such that the output sine wave form of inverter is made pulse free pure sine wave. As a result the harmonic distortion of injected sine wave is reduced(THD□ 3%). One of the advanced MPPT (say FOCV MPPT) is implemented to produce maximum power output from the available irradiation.

The overall system safety under variable grid conditions are studied and a frequency oriented control is provided. The grid frequency is monitored all the time and any variation of 3\% from fundamental value will cause breaker operation and the system will be isolated from the utility grid. It also ensures safety during working at utility side.

For advanced operation the whole system will be able to work as a STATCOM device for the reactive power compensation on the grid line. The control is provided by controlling the PCC voltage for the injection of reactive current to the line.

The GTSI part is simulated and the output is verified at various test conditions such as variable loads and illumination. The outputs are verified. By variation in power, the excess power is supplied to the utility and if the power is deficient, the power is drained from the utility.

The PV STATCOM will become a better possibility for advanced power flow enhancement so that the possibilities of power production and grid power flow control using a single system. So in future the complete system can be designed, simulated and studied under different grid conditions including faults.

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