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Power Sharing using Phase Shift Mechanism in Grid Interactive Photo-voltaic Power Systems

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Abstract: Finite amount of fossil fuels meant more reliance on energy produced by renewable sources. Solar energy is considered as a game changer all over the world due to its cleanliness and easiness to fetch; different methods are employed globally to increase solar consumption in way that would significantly reduce utility consumption without - of course - compromising on the continuous power supply to the grid. Synchronizing solar system with the grid is a concept that requires synchronization of AC bulk energy source with the limited DC energy source. Complete synchrony of both sources will ensure continuous power supply to the load with maximum power provided by solar energy, and only deficit power being contributed by utility; surplus power will also find its way to the grid ensuring no power is wasted. Phase angle between grid voltage and inverter voltage is changed which changes power share of both the sources accordingly. MPPT mechanism is incorporated to ensure maximum efficient utilization of solar source. Simple design with low-cost hardware paves way for its easier implementation without much hiccups.

Keywords: GTI, Inverter, P&O, MPPT, PV, DC, AC, SPWM, MPP, PWM, MOSFET.

I. INTRODUCTION

The basic idea behind Grid-Tied solar systems is to share power as effectively and as conveniently as it gets. Renewable power production is becoming a trend these days with more and more methods are being employed to produce cleanest energy at very much affordable overall cost. Grid tied solar systems uses solar as a source of energy; it makes sure the best possible synchronization between solar energy source and bulk source – AC utility. Grid tied solar systems ensure maximum available power transfer from solar source and any remaining amount from bulk energy source in case our demand exceeds solar production only. Also, synchronization is such that that any surplus energy is fed back to the grid through incorporated phase shift mechanism of transfer power. These systems work efficiently in off-grid configuration as well as on-grid configuration, unlike most solar-grid systems which go into halt once utility fails. Our main focus lies in sharing active and reactive power between sources to deliver power to the load depending on how much solar power is available to feed the load. This scheme is only effective if all of the solar power produced, is also fed to the load so that the burden does not only lies on the shoulders of utility. Effectively designed Grid-tied solar system will not only utilize solar energy to drive the load, but also, aims to reduce utility bill since portion of power is also shared by our own installed renewable source of energy.

The flow of active and reactive power, in case of coupled sources, will depend upon which signal is leading and which signal is lagging. Remember, one power source is AC (utility), other is DC (converted in to AC using GTI). In this power sharing technique, load angle – angle between inverter voltage and grid voltage is made to lead/lag depending on how much power we want from which source to control power flow to the load. In this grid interactive mechanism, power sharing is made possible by controlling the grid voltage and varying it phase angle. This variation of phase angle from 0 to 90 degrees will see both of these waves lead/lag one another depending on our reference wave, which in result decides how much power is shared by which source. However, it is not as easier and simpler as it may sound. The equations governing the flow of active and reactive power are shown in equation (1) and (2). In order to operate solar panels at maximum efficiency, MPPT algorithm P&O is incorporated which makes sure our system works at maximum current and voltage peaks.

II. METHODOLOGY

Basically, this system comprises of three units: Power Sharing Unit, Inverter Unit, and Solar Module Unit. This is represented by this block diagram. Each unit contains sub elements which are pictured too in Fig. 1.

A. Power Share Block

In order to sense the grid voltage, frequency and phase shift, controller has to be employed. To meet its requirements, we first need to step down grid voltages from 220 volts RMS values to 5 volts peak to peak so that it can be applied easily to the controller. This is achieved through simple step down circuitry, which is followed by the analogue phase shifter for shifting the phase of reference wave. Using high pass filter at the non-inverting input and a negative feedback loop to compensate for the filter attenuations makes the desired ***All Pass Filter*** response, like in Fig. 2. When input frequency is 1/2*pi*RC, the circuit introduces a phase shift up to 90 degrees which is of our main concern as in Fig. 3. In case of simple RC high pass filter, the circuit has a phase shift that goes from -180 at 0 Hz, and 0 at high frequency, and -90 at 1/RC (all values in degrees). The resistor may be made variable resistor to allow the adjustment of the delay at a particular frequency. The value of phase shift in the grid wave can be controlled manually by a variable resistor or Digi pot can also be implemented. All pass filters is then followed by Clamper circuit to make the wave appear only in the positive region and controller compatible. This wave is then put into controller (Arduino), which has code plugged in, for sampling and generation of SPWM. Figure 4, shows the final output waveform which comprises of Original Input Wave, Shifted Wave & Clamped Wave.

A1. Design Equations

Consider the above RC high pass filter with feedback loop. In order to find the transfer function of this, let us first find the transfer function of high pass attached.

Let the voltage across resistor R in the above figure is Vo.

$$\frac{Vo}{Vin} = H(jw) = H(high\,pass) = \frac{R}{R+\frac{1}{jwC}}$$

$$H(high\,pass) = \frac{jwRC}{1+jwRC}$$

$$H(s = jw) = \frac{sRC}{1+sRC}$$

Or, we can write,

$$\frac{Vo}{Vin} = \frac{sRC}{1+sRC}$$

Let us say, VO =Vr_1 (across resistor R_1), applying KCL at node of R_1 (inverting node),

$$\frac{Vin - Vr1}{R1} = \frac{Vr1 - Vout}{R1}$$

$$Vin - Vr1 = Vr1 - Vout$$

$$Vout = 2Vo - Vin$$

$$Vout = 2((Vin * H(highpass) - Vin)$$

$$\frac{Vout}{Vin} = 2 * H(highpass) - 1$$

$$Ht(s) = \frac{Vout}{Vin} = 2 * \frac{sRC}{sRC+1} - 1$$

$$Ht(s) = \frac{sRC-1}{sRC+1}$$

$$Ht(s) = \frac{s-\frac{1}{RC}}{s+\frac{1}{RC}}$$

This is the final transfer function of above all pass configuration with high pass at the non-inverting terminal and feedback loop at the inverting terminal.
Now, for phase shift,

$$Phase\ shift\ (\theta) = ARCtan\,(-w/wo) - ARC\tan(w/wo)$$

$$\theta = 180\ (\mathrm{deg}) - ARCtan\left(-\frac{w}{wo}\right) - ARC\tan\left(\frac{w}{wo}\right)$$

$$\theta = 180\ (deg) - 2 * ARCtan\left(-\frac{w}{wo}\right)$$

$$\theta = 180\ (deg) - 2 * ARCtan\,(RC * 2 * pi * F)$$

$$RC = 2 * pi * F * \tan(-\theta * \frac{1}{2})$$

B. Solar Panel Block

Solar Panel Unit comprises of the blocks shown in Fig 5. It comprises of sensors, DC to DC converter & a micro-controller section to control the circuitry. The sensors connected to the solar panel feeds the real time data to the micro-controller, which is Arduino MEGA 2560 in our case, the micro-controller has a MPP algorithm embedded in it and thus produces a PWM signal which goes into our DC-DC Buck Converter that generated an output which is suitable to charge our batteries or drive a DC load as per requirement as depicted in the block diagram too. Synchronous buck converter is same as normal buck converter the only difference is that it comprises of two MOSFET's, Inductor and Capacitor. The PWM signal is given to the MOSFET's gates. The two

MOSFET’s cannot be switched at the same time so that is why some synchronization is required thus called synchronous buck converter. Next step is the selection of MPPT algorithm. The entire MPPT algorithm requires sensing inputs that’s the raw value of current and voltages. In P&O the controller varies the value of voltage and current is kept constant to increase power. The value of V is increased until the maximum power point is reached. If the value of power is less than the previous value then value of V is decreased. This process of increasing and decreasing voltage is continued until maximum power is reached. The P&O algorithm block diagram is shown in fig 6. Firstly the values of voltages and currents are measured. Initially the values of V and I are zero. By multiplying these two values the current value of power is calculated. The algorithm then compares the current power with the previous power. If the value of current value of power is greater than previous then the value of V is increased and is continued until the current value of power is less than that of the previous. Now the value of voltage is decreased and in this way our algorithm will continue to oscillate around the maximum power point value as shown in fig 7. The operating voltage of the solar module is perturbed by a constant increase in value, and the variation of power, P is observed. If the power P has a positive value, then it is assumed that it has moved towards the MPP value. Thus the same phenomena is continued. If P becomes negative, the operating point has moved away from the MPP, and the direction of perturbation is to be changed, so that it can move towards the MPP value. Next is the calculation of L & C using equation (3) and (4).

C. Inverter Unit

Our third unit is inverter circuitry which is important as we have to convert direct voltage into alternating voltage. Inverter takes dc input and changes it into alternating quantity. LC filter is then followed by Inverter to smooth the ripples and edges, and make waveform look alternating. Inverter has 300v dc, which is boosted form of solar panel output, and clock signal (PWM) to derive its components. PWM is generated by Arduino Code. The output is shown in Fig 8. In this configuration, four MOSFET’s are used. By controlling these MOSFET configuration (positive, negative, zero potential) voltage can obtained across the load. Switching of MOSFET’s is done according to the given table 1. By using the P-channel MOSFET on high side and N-channel MOSFET on lower side is easy but when using all N-channel MOSFET and FET driver it lower (on) resistance is obtained which results in reduction of power loss. When using all N-channel MOSFET and by turning on a high side MOSFET, it leads to voltage higher than the switching voltage. This problem is removed by using driver circuit for this particular reason. Another problem which was encountered, the drain terminal of high side MOSFET is often connected to high voltage in system, this create problem because gate terminal should be always greater than 10V, so that the drain terminal for MOSFET start conducting. For this MOSFET driver is used through charge pumps or bootstrapping techniques. All MOSFET are N-channel because their current handling capability is better. To reduce this problem of driving high side N- channel MOSFET the driver use external source to charge the bootstrapping capacitor which is connected between the Vcc and source terminals. The bootstrap capacitor give gate charge to high side MOSFET. When switch start to conduct, the capacitor maintains a potential difference so that the MOSFET is fully turned on. The chart below in table 2 represents the operation of inverter at no load and on-load. In this way, the designing of the inverter unit is achieved. System design is now complete with all three units being designed. All three units now only needs interconnection to form a complete grid-interactive solar system.

III. EQUATIONS, GRAPHS & TABLES

$$P = \frac{|Vinv| * |Vgrid| * \ sin\delta}{Z} \qquad (1)$$

$$Q = \frac{|Vinv^2\ |}{Z} - \ \frac{|Vinv| * |Vgrid| * \ cos\delta}{Z} \qquad (2)$$

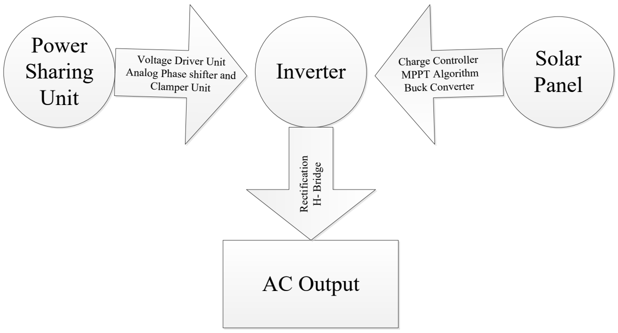

Figure 1: Overall System Block Diagram

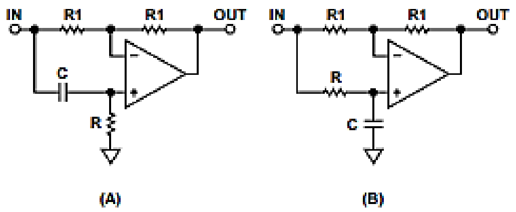

Figure 2: All Pass Filter

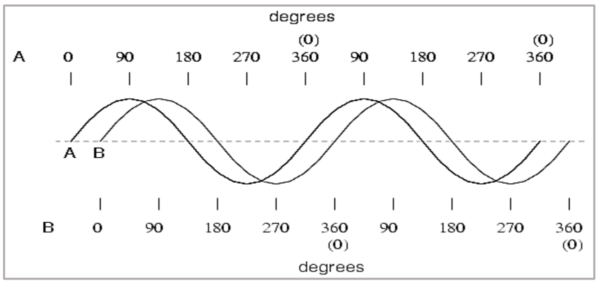

Figure 3: Phase Shifted Waveform

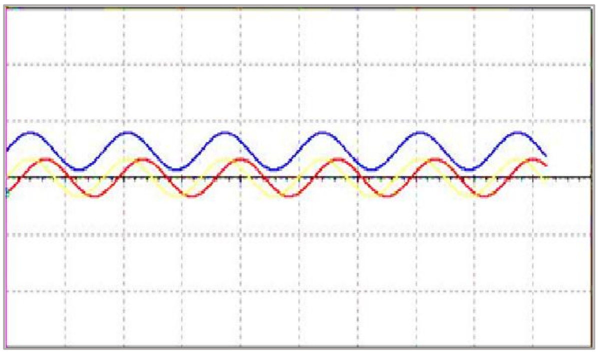

Figure 4: Final output Phase Shifted waveform.

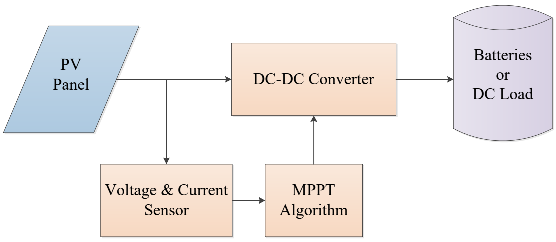

Figure 5: Block Diagram of Solar Panel Unit

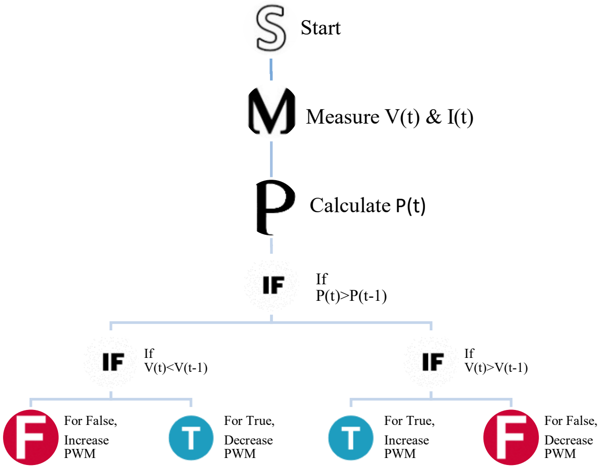

Figure 6: P&O Algorithm

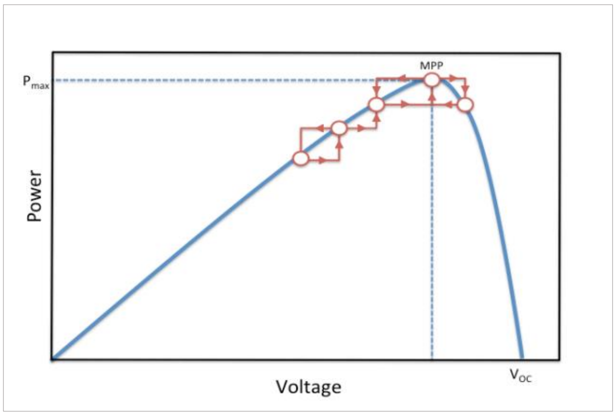

Figure 7: Maximum Power Point Tracking

$$L = (Vin - Vout) * D * \frac{1}{Fsw} * \frac{1}{dI} \tag{3}$$

$$C = \frac{dI}{(8\ x\ Fsw\ x\ dV)} \tag{4}$$

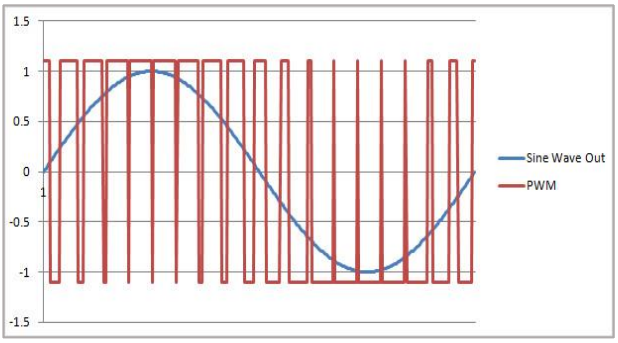

Figure 8: PWM for Sine Wave Inverter

Table 1: MOSFET Switching.

Low Side Left	Low Side Right	High Side Left	High Side Right	Voltage Across Load
Off	On	On	Off	Positive
On	Off	Off	On	Negative
Off	Off	On	On	Zero potential
On	On	Off	Off	Zero potential

Table 2: Operation of Inverter.

DC (V)	AC (At no Load)	AC with Load
60	80	20
100	125	85
150	170	110
200	235	140
250	260	200
315	330	235

IV. CONCLUSION

In a country like Pakistan, this grid-interactive solar system could become very handy. It would help in reducing the utility burden by injecting its own solar capacity into the system. How much energy we take from the grid is controlled and therefore, we are actually making our system much smarter and efficient, and also capable to make its own decisions.

REFERENCES

[1] Biolek, D. and V. Biolkova, First-order voltage-mode all-pass filter employing one active element and one grounded capacitor. Analog Integrated Circuits and Signal Processing, 2010. 65(1): p. 123-129.

[2] 3. Gift, S., The application of all-pass filters in the design of multiphase sinusoidal systems. Microelectronics Journal, 2000. 31(1): p. 9-13.

[3] Traylor, K.B. and J. Fang, Method and apparatus for DC offset correction. 2001, Google Patents.

[4] 5. Fernandez, V.A. and G. Gerosa, Apparatus for adjusting DC offset voltage. 1991, Google Patents.

[5] Component Reliability for Electronic Systems By Titu I. Băjenescu, Marius I. Bâzu

[6] Component Reliability for Electronic Systems By Titu I. Băjenescu, Marius I. Bâzu

[7] Efficiency of synchronous versus nonsynchronous buck converters by Rich Nowakowski

[8] Arduino Peak Power Tracking Solar Charger by Tim Nolan, http://www.timnolan.com/uploads/Arduino%20Solar/ppt.pde

[9] Solar_array_controller_needs_no_multiplier_to_maximize_power

[10] http://www.edn.com/article/471969/

[11] Photovoltaic Charge Controller Using Mppt Algorithm, Rakshit Shetty, Aniket Upadhyay, Mahesh Shinde, Chirag Rajput, Prof. Martand Jha, International Journal of Engineering and Technical Research (IJETR)

[12] LC Selection Guide for the DC-DC Synchronous Buck Converter,

[13] http://www.onsemi.com/pub_link/Collateral/AND9135-D.PDF

[14] [9] Photovoltaic MPPT Charge Controller, http://eecs.ucf.edu/seniordesign/fa2011sp2012/g10/docs/PMCC_Group%2010_SD1.pdf

[15] An Efficient MPPT Solar Charge Controller, Dr.Anil S. Hiwale, Mugdha V.Patil ,Hemangi Vinchurkar, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

[16] Design of Solar Charge Controller by the use of MPPT Tracking system, Ms. Arjyadhara Pradhan , Dr S.M Ali, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering.

[17] Design and Implementation of Solar Charge Controller with MPPT Algorithm Using Synchronous Buck Converter,

[18] https://www.academia.edu/26270282/Design_and_Implementation_of_Solar_Charge_Controller_with_MPPT_Algorithm_Using_Synchronous_Buck_Converter_Arduino_Based

[19] https://www.academia.edu/17314365/Verification_of_Perturbation_and_Observation_Algorithm_for_PhotoVoltaic_MPPT_Systems_Using_MatlabSimulink

[20] Farid, Ghulam, et al. "Verification of Perturbation and Observation Algorithm for Photo-Voltaic MPPT Systems Using Matlab/Simulink."

[21] Maximum Power Point Tracking Simulation for Photovoltaic Systems Using Perturb and Observe Algorithm, Samer Alsadi, Basim Alsayid, International Journal of Engineering and Innovative Technology

[22] Simulation and Analysis of Perturb and Observe MPPT Algorithm for PV Array Using ĊUK Converter, Tekeshwar Prasad Sahu , T.V. Dixit and Ramesh Kumar.

[23] Design and Development of Solar Pump using MPPT (P&O) Algorithm, Sushil Samantra , Arupananda Pattanaik, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering.

[24] Design and Simulation of Intelligent Control MPPT Technique for PV Module Using MATLAB/ SIMSCAPE, http://www.ijareeie.com/upload/2013/september/45_Design.pdf.