

Generation of Control Signals for an AC – DC Converters for a Hybrid Charging System

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Abstract -- A hybrid generator with a PV energy conversion system is proposed with super capacitors and lead acid batteries in a DC- coupled structure. The objective of this system is to present works focuses on the strategy which makes it possible to ensure a high battery state of charge and overcharge security by designing a dedicated local control system. A dynamic model and a control design of the power system studied are proposed in this paper. Simulation of control characteristic was carried out using matlab and experimental results illustrate the performance obtained. It also shows the application of rectifier circuit in the hybrid system limited to purely resistive load. This paper proposes a single power conversion AC – DC converter with high power factor and high efficiency. The proposed converter is derived by integrating a half wave thyristor rectifier with resistive load and a series resonant active DC – DC converter or charge controller for the PV installation.

Indexed Terms: AC (Alternating Current), DC (Direct Current), Hybrid power system, PV (Photo voltaic), converters.

I. INTRODUCTION

The use of rectifiers in industrial applications started at the era of mercury converters with the electromechanical contact converter. DC machines are common in day to day use. But the supply that we get from power companies is AC. To use those machines AC supply has to be turned into DC supply by the use of a rectifier. A rectifier is an electrical device that converts the incoming AC (alternating current) from a transformer or any other ac power source to pulsating DC (direct current). Rectifier may be made of diodes, solid states, vacuum tube, mercury arc valves and other components. All rectifier circuits may be classified into one of two categories: i. half wave rectifiers and ii full wave rectifier. Rectifiers are also used for 3-phase inputs. Rectifiers can further be classified into two categories i.e. controlled and uncontrolled rectifier. The dc output always remain

constant if ac input voltage is constant in an uncontrolled rectifier whereas the output voltage can be controlled in a controlled rectifier. Rectifiers are widely used in non-linear loads which are connected with distribution systems which plays an important role in power system network (ex: UPS, discharge lamp, television, computer, fax machines, ferromagnetic devices, arc furnaces, energy savers etc.). A further application of the rectifier is driving a DC motor. Speed control in DC motor is an important issue. With time the need of flexible speed control for motor is becoming essential. One way to control the speed of the motor is by varying its input voltage. In modern systems most of the conversions are performed with semiconductor switching devices such as diodes, thyristor and transistors. An AC to DC converter is the most commonly used power electronics devices found in many consumer electronics device (e.g. television, computer, battery chargers etc.). Power electronics devices are characterized being either a short circuit or an open circuit. As the switching capability combined with efficiency and performance making power electronics a fast growing area in electrical engineering. At the same time it is desirable because of relatively small power loss in the device. An AC to DC converter enables integrated circuits to operate from a 50/60 Hz AC line voltage by converting the AC signal to a DC signal of the suitable voltage. Also photovoltaic (PV) generators are designed in order to generate a maximum power to the grid. Because of the stochastic nature of the PV power output, large developments of grid –connected PV systems involve large fluctuations of frequency, power and voltage in the grid. Since some countries have adopted feed-in tariffs for grid-connected PV systems, such problems are now critical and the control of energy quality becomes more important than before. Active distributed generators (DGs) have the potential to provide ancillary services under these circumstances. For example, they may have several functions as frequency control,

instantaneous reserve, emergency supply, peak shaving, ... to provide these services, the real and reactive grid power produced from PV generators have to be controlled [1], [2]. Hence, storage units (batteries, super capacitors etc.) or/and other energy sources (wind generator, diesel units etc.) can be used to compensate the lack of power or store excess power [3], [4]. Thus this paper aims on designing a rectifier circuit that can supply a voltage as required and can be adjusted if necessary even after the operation starts.

II. STUDY OF RECTIFIERS

Classification of Rectifiers

I) Single phase

a) Half-wave: i) Controlled ii) Uncontrolled

b) Full-wave: i) Controlled ii) Uncontrolled

II) Three Phase

a) Half-wave: i) Controlled ii) Uncontrolled

b) Full-wave: i) Controlled ii) Uncontrolled

2.1 Single phase rectifier

(a) **Half-Wave Rectifier:** In half-wave rectifier, half of the ac cycle (either positive or negative) pass, while during the other half cycle the diode blocks the current from flowing. Basic half-wave rectifier circuit may be constructed with a single diode in a one phase supply, or three diodes with a three-phase supply. Such circuits are known as half – wave rectifier as they only work on half of the incoming ac wave.

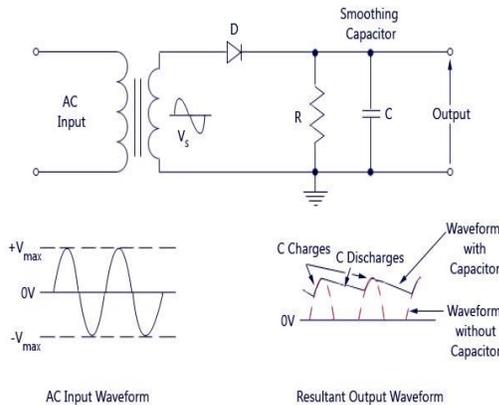


Fig. 2.1: Half Wave Rectifier

(b) **Full-Wave Rectifier:** A full-wave rectifier converts the whole incoming ac wave so that both halves are used to cause the output current to flow in same direction (either positive or negative). Full-wave

rectification is more efficient because it converts both polarities of input waveform to DC. A full-wave rectifier circuit requires four diodes instead of one needed for half-wave rectification. For the arrangement of four diodes the circuit is called a diode bridge or bridge rectifier.

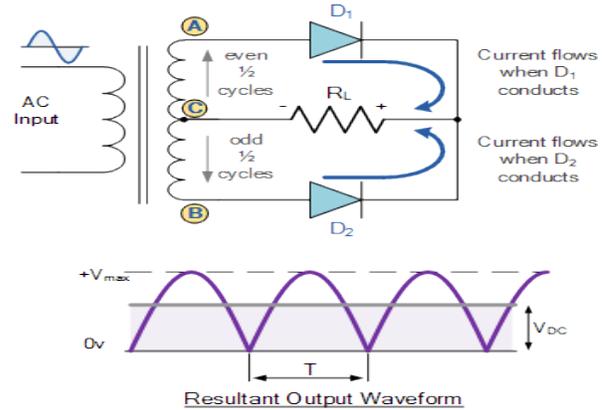


Fig. 2.2: Full Wave Rectifier

Like the half wave circuit, a full wave rectifier circuit produces an output voltage or current which is purely DC or has some specified DC component. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average (DC) output voltage is higher than for half wave, the output of the full wave rectifier has much less ripple than that of the half wave rectifier producing a smoother output waveform. In a Full Wave Rectifier circuit two diodes are now used, one for each half of the cycle. A multiple winding transformer is used whose secondary winding is split equally into two halves with a common centre tapped connection, (C). This configuration results in each diode conducting in turn when its anode terminal is positive with respect to the transformer centre point C producing an output during both half-cycles, twice that for the half wave rectifier so it is 100% efficient as shown above. The full wave rectifier circuit consists of two power diodes connected to a single load resistance (R_L) with each diode taking it in turn to supply current to the load. When point A of the transformer is positive with respect to point C, diode D_1 conducts in the forward direction as indicated by the arrows. When point B is positive (in the negative half of the cycle) with respect to point C, diode D_2 conducts in the forward direction and the

current flowing through resistor R is in the same direction for both half-cycles. As the output voltage across the resistor R is the phasor sum of the two waveforms combined, this type of full wave rectifier circuit is also known as a “bi-phase” circuit.

2.2 The Full Wave Bridge Rectifier

Another type of circuit that produces the same output waveform as the full wave rectifier circuit below, is that of the full wave bridge rectifier. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop “bridge” configuration to produce the desired output. The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.

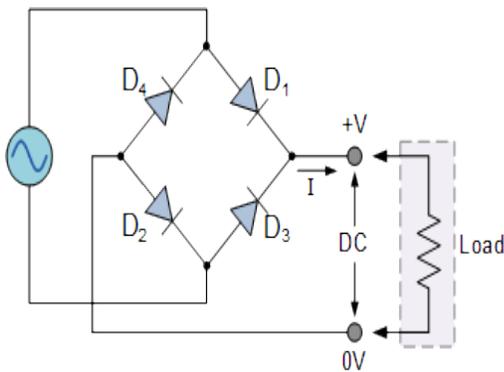


Fig. 2.3: Full wave Bridge Rectifier

The four diodes labelled D₁ to D₄ are arranged in “series pairs” with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D₁ and D₂ conduct in series while diodes D₃ and D₄ are reverse biased and the current flows through the load as shown below.

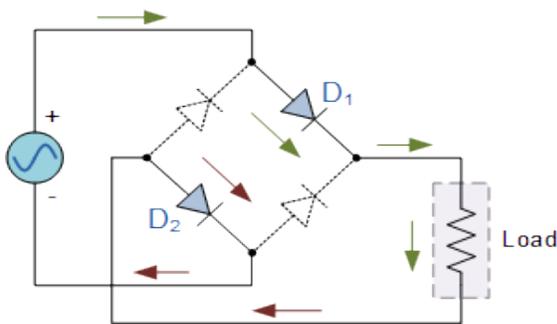


Fig. 2.4: The Positive Half-cycle

During the negative half cycle of the supply, diodes D₃ and D₄ conduct in series, but diodes D₁ and D₂ switch “OFF” as they are now reverse biased. The current flowing through the load is the same direction as before.

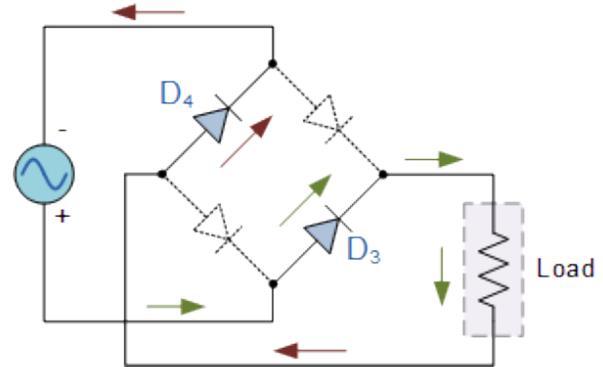


Fig. 2.5: The Negative Half-cycle

2.3 The Smoothing Capacitor

We saw in the previous section that the single phase half-wave rectifier produces an output wave every half cycle and that it was not practical to use this type of circuit to produce a steady DC supply. The full-wave bridge rectifier however, gives us a greater mean DC value ($0.637 V_{max}$) with less superimposed ripple while the output waveform is twice that of the frequency of the input supply frequency. We can improve the average DC output of the rectifier while at the same time reducing the AC variation of the rectified output by using smoothing capacitors to filter the output waveform. Smoothing or reservoir capacitors connected in parallel with the load across the output of the full wave bridge rectifier circuit increases the average DC output level even higher as the capacitor acts like a storage device as shown below.

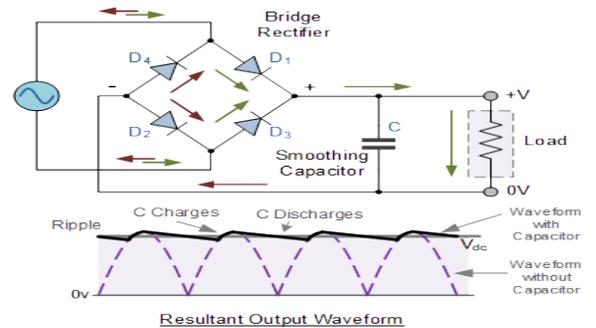


Fig. 2.6 Full wave Bridge Rectifier with Smoothing Capacitor

The smoothing capacitor converts the full-wave rippled output of the rectifier into a more smooth DC output voltage. This device as shown is very much incorporated in various systems such as the hybrid power system. Before analysing the AC-DC conversion in the hybrid system we need to understand the complete system. A stand-alone hybrid power system is used for this purpose.

III. STAND-ALONE HYBRID POWER SYSTEM

Hybrid power systems combine multiple sources to deliver non intermittent electric power.

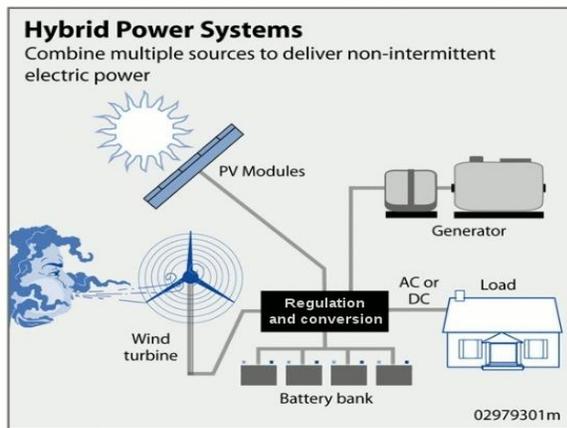


Fig. 3.1: Schematic of hybrid system [5]

Stand-alone power system (SAPS), also known as remote area power supply (RAPS), is an off-the-grid electricity system for locations that are not fitted with an electric distribution system. Typical SAPS include one or more methods of electricity generation, energy storage and regulation. Electricity is typically generated by one or more of the following methods: Photovoltaic system using solar panels, Wind turbine, geothermal sources, micro hydro, diesel or biofuel generator, thermoelectric generator. Storage is typically implemented as a battery bank, but other solutions exist including fuel cells. Power drawn directly from the battery will be direct current extra low voltage (DC ELV), and this is used especially for lighting as well as for dc appliances. An inverter is used to generate AC low voltage, which more typical appliances can be used with [5] [6].

IV. SIGNAL ANALYSIS

Here we look into the various forms of rectifications so as to have a precise approach of implementation if designing for related loads in a hybrid system and otherwise.

4.1 Single phase half wave controlled rectifier with Resistive Load

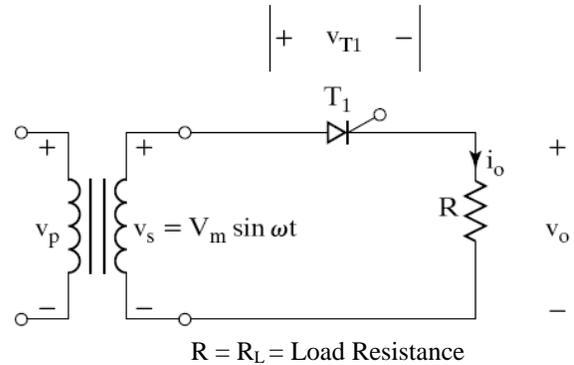


Fig.4.1: Single phase Half-wave Thyristor converter with a Resistive Load

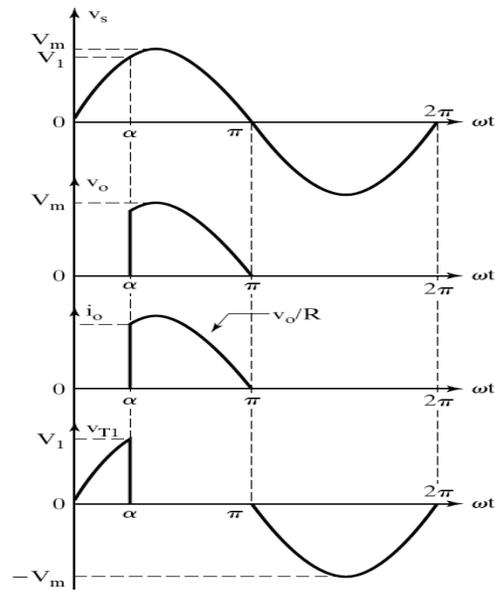


Fig.4.2: waveforms of a single phase half wave controlled rectifier with Resistive Load

$$V_{dc} = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_o \cdot d(\omega t) \tag{1}$$

$$V_o = V_m \sin \omega t$$

$$V_{dc} = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m \sin \omega t . d(\omega t)$$

$$V_{dc} = \frac{V_m}{2\pi} \int_{\alpha}^{\pi} \sin \omega t . d(\omega t)$$

$$V_{dc} = \frac{V_m}{2\pi} [-\cos \omega t]_{\alpha}^{\pi}$$

$$V_{dc} = \frac{V_m}{2\pi} [-\cos \pi + \cos \alpha] ; \cos \pi = -1$$

$$V_{dc} = \frac{V_m}{2\pi} [1 + \cos \alpha] \tag{2}$$

$$V_m = \sqrt{2}V_s$$

Taking $V_m = 220V$, $\alpha = 0^\circ - 180^\circ$

Table 1.0: Relative V_{dc} at varying firing angle

S/N	α	V_{dc} (V)	%
1	0°	V_{dm}	100 V_{dm}
2	30°	$0.9330 V_{dm}$	93.30 V_{dm}
3	60°	$0.750 V_{dm}$	75.0 V_{dm}
4	90°	$0.50 V_{dm}$	50.0 V_{dm}
5	120°	$0.25 V_{dm}$	25.0 V_{dm}
6	150°	$0.0669 V_{dm}$	6.698 V_{dm}
7	180°	0	0

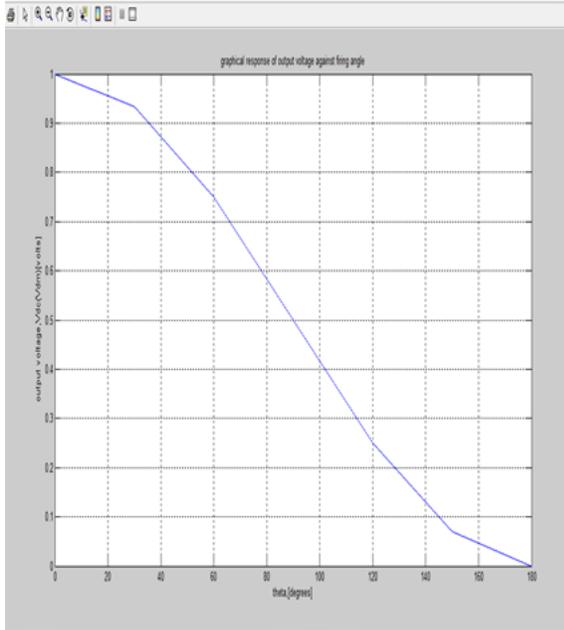


Fig.4.3: Control Characteristic

The maximum average (dc) output voltage is obtained when $\alpha = 0$ and the maximum dc output voltage $V_{dc(max)} = V_{dm} = \frac{V_m}{\pi}$.

The average dc output voltage can be varied by varying the trigger angle α from 0 to 180° (π radians). While normalizing the dc output voltage with respect to V_{dm} , the normalised output voltage $V_{dcn} = \frac{V_{O(dc)}}{V_{dc max}} = \frac{V_{dc}}{V_{dm}}$

4.2 RMS value of a single phase half wave controlled rectifier with resistive load

$$V_{O(rms)} = \left[\frac{1}{2\pi} \int_0^{2\pi} V_o^2 . d(\omega t) \right] \tag{1}$$

(1)

Output voltage $V_o = V_m \sin \omega t$

For $\omega t = \alpha$ to π .

$$V_{O(rms)} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 d(\omega t) \right] \tag{2}$$

(2)

$$V_{O(rms)} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 d(\omega t) \right]^{\frac{1}{2}}$$

Note that; $\sin^2 \omega t = \frac{1 - \cos 2\omega t}{2}$ thus

$$V_{O(rms)} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \frac{1 - \cos 2\omega t}{2} d(\omega t) \right]^{\frac{1}{2}} \tag{3}$$

$$V_{O(rms)} = \left[\frac{V_m^2}{4\pi} \int_{\alpha}^{\pi} 1 - \cos 2\omega t d(\omega t) \right]^{\frac{1}{2}}$$

$$V_{O(rms)} = \left[\frac{V_m^2}{4\pi} \left\{ \int_{\alpha}^{\pi} d(\omega t) - \int_{\alpha}^{\pi} \cos 2\omega t d(\omega t) \right\} \right]^{\frac{1}{2}}$$

$$V_{O(rms)} = \left[\frac{V_m^2}{4\pi} \left\{ (\omega t) \Big|_{\alpha}^{\pi} - \left(\frac{\sin 2\omega t}{2} \right) \Big|_{\alpha}^{\pi} \right\} \right]^{\frac{1}{2}}$$

$$V_{O(rms)} = \frac{V_m}{2} \left[\frac{1}{\pi} \left\{ (\pi - \alpha) - \left(\frac{\sin 2\pi - \sin 2\alpha}{2} \right) \right\} \right]^{\frac{1}{2}}$$

$\sin 2\pi = 0$; hence we get

$$V_{O(rms)} = \frac{V_m}{2} \left[\frac{1}{\pi} \left\{ (\pi - \alpha) + \frac{\sin 2\alpha}{2} \right\} \right]^{\frac{1}{2}}$$

$$V_{O(rms)} = \frac{V_m}{2\sqrt{\pi}} \left\{ (\pi - \alpha) + \frac{\sin 2\alpha}{2} \right\}^{\frac{1}{2}} \tag{4}$$

Take $\pi = 180^\circ$, $V_m = 220V$

Table 2.0: Relative V_{rms} at variable firing angles

S/N	α	$V_{O(rms)}$ (V)
1	0°	110.00
2	30°	100.56
3	60°	89.98
4	90°	77.78
5	120°	63.28
6	150°	44.58
7	180°	0

Similarly, $V_{o(rms)}$ is at maximum when $\alpha = 0^\circ$

5.0 Conclusion

This paper on signal generation for hybrid charger only highlights the hybrid source stand alone for the analysis of the control signal generation restricted to ac – dc half wave controlled converter with resistive load by designing from the basic. And the mathematical tool (Matlab) used for the graphical response to this effect shows conformity with the performance as analysed. It was clearly seen that the maximum output dc voltage was achieved at zero level of the firing angle, while at 180° of the firing angle, the minimum output dc voltage was achieved.

REFERENCES

- [1] P.G. Barbosa, L.G.B. Rolim, E.H. Wantabe, R. Hanitsch, “control strategy for grid-connected DC-AC converters with load power factor correction, Generation”, Proc. IEE Transmission and Distribution, Vol. 145, Issue 5, pp. 487 – 491, Sep 1998.
- [2] H. Yu, J Pan, A. Xiang, “A multi – function grid-connected PV system with reactive power compensation for grid”, solar Energy, vol. 79, iss. 1, pp 101-106, July 2005.
- [3] G. Delille, B. Francois, A review of some technical and economic features of energy storage technologies for distribution system integration, Ecological engineering and environment protection, pp. 40-48, vol. 1, ISSN 1311-8668, 2009.
- [4] O. Gabriel, C. Saudemont, B. Robyns, M. Radulescu, “control and performance evaluation of a flywheel energy-storage system associated to a variable-speed wind generator”, IEEE Trans. on Ind. Electron, Vol. 53, n^o 4, pp. 1074-1085, 2006
- [5] “A stand-alone photovoltaic system”, renewable-energy –sources.com. Archived

from the original on 2011-07-13. Retrieved 2011-07-21.

- [6] “A stand-alone photovoltaic system, case study: A Residence in Gaza” (pdf). trisanita.org. Archived from the original (pdf) on 2012-04-26. Retrieved 2011-07-21.

Matlab Programme

```
%program to illustrate control characteristic of single
phase half wave
%controlled rectifier
%Vdc output voltage in V
%Vdm = Vm/pie
%Vm is peak input supply voltage in V
%theta is firing angle of thyristor in degree
%Vdc = ((Vm/2pie)*(1+cos theta))
Vm = 220;
theta = [0 30 60 90 120 150 180];
Vdc = [1 0.9330 0.750 0.5 0.25 0.0699 0];
Plot (theta,Vdc)
grid on
xlabel ('theta, [degrees]')
ylabel ('output voltage, Vdc (Vdm)[volts]')
title ('graphical response of output voltage against
firing angle')
```