

Maximum Power Point charge Controller for DCDC Power Conversion in Solar PV System

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Abstract

A charge controller that includes an input interface that receives input DC electrical signals. A converter section converts the input DC electrical signals to output DC electrical signals. Control means is operably coupled to the converter section. The control means includes means for operating the converter section at an estimated maximum power point of the input DC electrical signals. The estimated maximum power point is derived by a novel control scheme that quickly adapts to changing conditions and thus affords optimum energy harvest from the source and improved energy conversion efficiencies.

Index terms— Charge Controller, DC, AC, PV, Solar, PWM, MPPT, SHS.

1 I. Introduction

Photovoltaic production becomes double every two years, increasing by an average of 48 percent each year since 2002. For this reason it becomes the world's fastest-growing energy technology [1]. Photovoltaic efficiency is very important for solar application. Photo-voltaic (PV) panels (sometimes referred to as photovoltaic modules) produce current at a specific voltage depending on the amount of solar radiation hitting the cells of the panel. The theoretical maximum amount of power from the sun at the earth's surface is about 1 KW per square meter at the equator on a clear day. To make the electrical power useful when the sun is not available, it must be stored, typically in batteries. The nature of the PV panels is that they have a specific Voltage \times Current curve that changes with the temperature and on the amount of sunlight or the angle at which the sun strikes the panel. Higher temperatures lower the voltage and more sunlight increases the output current. Distributed photovoltaic generation, in the form of roof-top domestic systems, is being installed at an increasing scale [2][3][4]. Significant power quality issues, especially voltage rise and voltage unbalance have been widely studied [5,6]. Higher penetrations or renewable generation within the distribution network can be achieved by the addition of intelligent control, storage or regulatory devices, [7].

In this case charge controller plays a vital role to protect the battery [8]. A series charge controller disables further current flow into batteries when they are full. A shunt charge controller diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full [8,9]. For increased system efficiency, it is desirable to operate PV panels at the voltage and current levels that produce the peak power, which is referred to as the Maximum Power Point [8,10]. The Proposed charge controller performs DC-DC power conversion typically utilizing Pulse Width Modulation (PWM) control of the electrical energy produced by the PV panels in order to transform such energy into a suitable form [11].

Figure iA : SHS with series controller [8] Figure iB : SHS with shunt controller Charge [8] A charge controller is needed in photovoltaic system to safely charge sealed lead acid battery [12]. The most basic function of a charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced [13]. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough [14]. This is especially important with sealed lead acid battery where we cannot replace the water that is lost during overcharging. Unlike Wind or Hydro System charge controller, PV charge controller can open the circuit when the battery is full without any harm to the

3 III. SUMMARY OF THE INVENTION

45 modules [15]. Most PV charge controller simply opens or restricts the circuit between the battery and PV array
46 when the voltage rises to a set point [16]. Then, as the battery absorbs the excess electrons and voltage begins
47 dropping, the controller will turn back on [17].

48 Figure iC : Basic image of controller and battery wiring [18] Charge controller has been regarded as one of the
49 important devices in stand-alone photovoltaic systems to prevent the battery from damage due to over-charging
50 and over-discharging [20]. Besides that, the unstable voltage from photovoltaic systems may spoil the load [19].
51 Studies show that the life time of the battery is degraded without using charge controller [21]. Therefore, a
52 charge controller should be designed to prolong the battery's life time and stabilize the voltage from photovoltaic
53 panel [22].

54 2 II. Background of the Invention a) Field of the Invention

55 This invention relates broadly to charge controllers that perform DC-DC power conversion. More particularly, this
56 invention relates to charge controllers for solar applications, including converting DC electrical energy provided
57 by photo-voltaic means for charging electrochemical batteries and for direct output [23][24][25][26][27][28][29]. b)
58 State of the Art Photo-voltaic (PV) panels (sometimes referred to as photovoltaic modules) produce current at a
59 specific voltage depending on the amount of solar radiation hitting the cells of the panel. The theoretical maximum
60 amount of power from the sun at the earth's surface is about 1 KW per square meter at the equator on a clear day.
61 To make the electrical power useful when the sun is not available, it must be stored, typically in batteries. The
62 nature of the PV panels is that they have a specific Voltage \times Current curve that changes with the temperature
63 and on the amount of sunlight or the angle at which the sun strikes the panel [30][31][32][33][34][35][36]. Higher
64 temperatures lower the voltage and more sunlight increases the output current.

65 For increased system efficiency, it is desirable to operate PV panels at the voltage and current levels that
66 produce the peak power, which is referred to as the Maximum Power Point. Loads such as batteries, on the other
67 hand, have a need for voltage and current which is independent and often different from what the PV panel is
68 producing. A charge controller (which can also be referred to as a charge regulator or regulator) is connected
69 between the PV panel(s) and the batteries or load in order to deal with this miss-match. The charge controller
70 performs DC-DC power conversion typically utilizing Pulse Width Modulation (PWM) control of the electrical
71 energy produced by the PV panels in order to transform such energy into a suitable form. For example, for
72 battery charging applications, the PWM control is used to adjust the voltage levels and current levels output
73 the battery [37][38][39][40][41][42]. More particularly, as the battery reaches full charge, the PWM control is
74 used to limit the voltage level supplied to the battery such a not to the harm the battery (i.e., inhibiting the
75 boiling of the electrolyte of the battery, which can destroy the battery). Early charge controllers were only able
76 to reduce the amount of voltage from the PV panels if too high for the batteries. Since the voltage from the PV
77 panels would be lower at high temperatures, the PV panels had to be over sized to ensure that the minimum
78 voltage at high temperatures would be at least as high as the battery to be charged plus voltage headroom
79 enough to force current into the battery [43][44][45][46][47][48]. At any temperature lower than the maximum,
80 the excess voltage from the PV panels would have to be discarded by the charge controllers. Because PV panels
81 are the most expensive component of the system, the need for extra (or larger) PV panels negatively impacted
82 the cost-effectiveness of such PV power systems [49][50][51][52][53][54][55].

83 Newer and more efficient charger controllers have emerged that provide a better match between the PV panels
84 and their load. Their goal is to use all the power from the PV panel(s) regardless of the voltage and current at any
85 amount of insolation or at any temperature. The newer charge controllers employ a DC to DC converter section
86 that is adapted to dynamically charge the battery (or to directly power a load) at the exact voltage and current
87 that is most appropriate for that battery (or load). Although the newer charge controllers provide improved
88 system efficiencies relative to the older models, they too often suffer from several shortcomings. More particularly,
89 the charge controllers are slow to adapt to changing conditions of the PV panel(s) over the course of any given
90 day, including low light conditions in the morning, evening and during cloud cover and also temperature changes
91 sometimes associated with the changes in insolation. The edges of clouds create particularly issues because they
92 cause a rapid change in lighting which may be followed by a relatively rapid change in temperature. Because
93 they do not quickly adapt to changing conditions, the charge controllers have limited efficiency, which results in
94 the need for extra (or larger) PV panels to be used for a given power output and high costs.

95 3 III. Summary of the Invention

96 It is therefore an object of the invention to provide a charge controller that quickly adapts to changing conditions
97 and thus affords improved energy conversion efficiencies. It is another object of the invention to provide such a
98 charge controller which can be adapted for use with a wide range of PV panels. It is a further object of the invention
99 to provide such a charge controller which can be adapted for use with a wide range of DC loads including batteries
100 for energy storage and DC-AC inverters for direct output. In accord with these objects, which will be discussed
101 in detail below, a charge controller is provided that includes an input interface that receives input DC electrical
102 signals. A converter section converts the input DC electrical signals to output DC electrical signals. Control
103 means is operably coupled to the converter section. The control means includes means for operating the converter
104 section at an estimated maximum power point of the input DC electrical signals [56][57][58][59][60][61][62]. The

105 estimated maximum power point is derived by a control scheme that includes the following operations: i) storing
106 an input voltage level corresponding to the estimated maximum power point; ii) varying the input voltage of the
107 input DC electrical signals over a sequence of sample points from a first voltage level to a second voltage level, and
108 deriving and storing an output current value of the output DC electrical signals at each sample point; iii) selecting
109 the maximum output current value from the output current values stored in ii), and identifying the particular
110 input voltage level corresponding thereto; and iv) varying the input voltage of the input DC electrical signals
111 over a sequence of sample points from the second voltage level to the particular input voltage level identified in
112 iii); and v) updating the stored input voltage level corresponding to the estimated maximum power point to the
113 particular input voltage level identified in iv).

114 In the preferred embodiment, for each given sample point in ii), the output current value for the sample point
115 is derived by averaging a plurality of output current measurements at the given sample point, and the first and
116 second voltage levels of ii) are derived from the measured open circuit voltage.

117 In another aspect of the invention, the control scheme carried out by the charge controller derives the estimated
118 maximum power point by the following operations: a) storing an input voltage level corresponding to the
119 estimated maximum power point; In the preferred embodiment, for each given sample point in b), the output
120 current value for the sample point is derived by averaging a plurality of output current measurements at the
121 given sample point, and the voltage differences between the sample points of b) is on the order of 100 mill volts
122 [63][64][65][66][67][68][69].

123 In yet another aspect of the present invention, the control scheme carried out by the charge controller updates
124 an input voltage level corresponding to an estimated maximum power point at a frequency of at least 500 Hz. It
125 will be appreciated that the maximum power point control operations of the present invention quickly adapt to
126 changing conditions and thus afford improved energy conversion efficiencies.

127 In the illustrative embodiment, the converter section comprises a buck converter topology having input reservoir
128 capacitance, at least one series switching element (e.g. an FET field effect transistor or IGBT insulated gate
129 bipolar transistor), at least one synchronous rectifier switching element, at least one inductor, and gate drive
130 circuitry that selectively switches the at least one series field effect transistor and the at least one synchronous
131 rectifier field effect transistor between ON and OFF states in response to pulse width modulation control signals
132 supplied thereto.

133 The control means (e.g., a microcontroller, microprocessor, digital signal processor or other control logic) is
134 operably coupled to the gate drive circuitry for varying the duty cycle of the pulse width modulation control
135 signals supplied to the gate drive circuitry in order to vary the input voltage level of the input DC electrical
136 signals. In the preferred embodiment, the control scheme carried out by the control means includes an MPPT
137 (Maximum Power Point Tracking) charging mode as well as a bulk charging mode, an absorption charging mode,
138 and a float charging mode.

139 In the MPPT charging mode, the control means regulates the input voltage of the input DC electrical signals
140 such that it is maintained at the input voltage level corresponding to the estimated maximum power point as
141 determined and stored by the control scheme. In the bulk charging mode, the control means regulates the output
142 current of the output DC electrical signals such that it is limited to a predetermined maximum current limit.

143 In the absorption charging mode, the control means regulates the output voltage of the output DC electrical
144 signals such that it is maintained at a predetermined absorption charging mode voltage level. In the float charging
145 mode, the control means regulates the output voltage of the output DC electrical signals such that it is maintained
146 at a predetermined float charging mode voltage level [70][71][72].

147 Additional objects and advantages of the invention will become apparent to those skilled in the art upon
148 reference to the detailed description taken in conjunction with the provided figures.

149 4 V. Detailed Description of the Preferred Embodiments

150 Turning now to FIG. 1, there is shown a functional block diagram of a solar power conversion system 1 which
151 includes a photo-voltaic (PV) array 3 capable of generating direct current electricity from incident solar radiation.
152 The photo-voltaic array 3 typically includes a number of PV modules 4 each comprising a number of series-
153 connected solar cells. The PV modules 4 can be connected in a parallel configuration as shown so that sufficient
154 power can be generated under minimum radiation conditions. The DC electrical signals generated by the PV array
155 3 are supplied to a number of series-connected components including protection circuitry 5, a charge controller
156 100 and a DC load 7. The protection circuitry 5 provides for protection against lightning strikes and other faults
157 (typically by shunting fault current to ground through MOVs and the like) and can also provide protection for
158 reverse-polarity faults. The protection circuitry 5 may also be responsible for limiting the maximum voltage
159 which can otherwise be higher than the maximum allowable voltage for the components in the next stage.

160 The open-circuit voltage (Voc) of the PV array 3 is about 20% to 30% higher than the operating voltage of
161 the same array and the increased voltages at low temperatures represent the worst case. The charge controller
162 100 converts the DC electrical signals generated by the PV array 3 into DC electrical signal suitable for output
163 to the DC load 7. The DC load 7 can be a bank of one or more batteries for energy storage and/or a DC-AC
164 inverter for direct output.

165 As shown in FIG. ??, the charge controller 100 includes a system housing 101 supports a synchronous buck
166 converter section 103 interfaced to a microcontroller 105. The synchronous buck converter section 103 utilizes

4 V. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

167 two switching elements (a series field effect transistor (FET) and a synchronous rectifier FET) to store energy
168 into (and extract energy from) an inductor. The series FET and the synchronous rectifier FET are driven by gate
169 drive circuitry to alternate between two states, a charging state and a discharging state. In the charging state, the
170 series FET is turned ON and the synchronous rectifier FET is turned OFF such that the inductor is connected
171 to a DC source voltage to store energy in the inductor. In the discharging state, the series FET is turned OFF
172 and the synchronous rectifier FET is turned ON in order to discharge the energy stored in the inductor to the
173 load. The gate drive circuitry that controls the operation of the series FET and the synchronous FET must
174 prevent both switches from being turned on at the same time, which is a fault known as "shoot-through". During
175 operation, the cooperation of the switching action of the series FET, synchronous rectifier FET and the inductor
176 reduce the DC source voltage level by a factor which is controlled by the duty cycle for the charging state of
177 both FETs. This duty cycle is controlled by pulse width modulation (PWM) control signals supplied to the gate
178 drive circuitry as is well known.

179 A multiphase synchronous buck converter is a topology whereby multiple buck converter circuits as described
180 above are placed in parallel between the source voltage and the load and controlled to out of phase with each
181 other. For example, two parallel circuits are set to switch such that one circuit is ON while the other is OFF.
182 In other words, the two circuits are 180 degrees out of phase with one another. The primary advantage of this
183 multiphase topology is that the load current can be split among the circuits or phases, thus allowing for increased
184 load currents. Another equally important advantage is that the output ripple is reduced by the number of phases,
185 thus allowing for easier filtering and lower output ripple. Each of these "phases" is turned ON at predetermined
186 intervals over the switching period.

187 In the illustrative embodiment shown, the buck converter section 103 employs a two phase topology with
188 two high current paths (phases A and B) each having input capacitance 107, a series FET 109, a Power supply
189 circuitry 129 can be connected to the positive (+) terminal of the output connector 127 as shown. The power
190 supply terminal transforms the DC voltage signal carried by the positive (+) terminal of the output connector
191 127 to internal bias voltage levels for supply to electrical components of the converter 100 as needed. Output
192 protection circuitry 129 can also be provided between the positive (+) and negative (?) terminals of the output
193 connector 127 to provide for overvoltage protection and possibly backflow current protection.

194 The microcontroller 105 supplies PWM control signals to the gate drive circuitry 113A, 113B of the two phases
195 via control lines 141A, 141B. These PWM control signals effectuate desired control over the duty cycle of the
196 charging state of the series FETs 109A, 109B for the two phases. The gate drive circuitry 113A, 113B for the
197 two phases also controls the operation of the synchronous rectifier FETS 111A, 111B for the two phases based
198 upon the PWM control signals supplied thereto. In the preferred embodiment, the series FETs 109A, 109B and
199 the synchronous rectifier FETs 111A, 111B of the two phases are switched at a frequency of 30 KHz or greater
200 when combined in order to keep noise above human hearing. For battery charging operations (e.g., Bulk Charging,
201 Absorption Charging, Float Charging), the microcontroller 105 controls duty cycle of the PWM control signals
202 supplied to the gate drive circuitry 113A, 113B (and thus controls the duty cycle of the charging state of the
203 series FETs 109A, 109B for the two phases) based upon the input voltage provided by the PV array, the output
204 voltage level and the output current level supplied to the DC load (i.e., the battery bank), and the battery
205 current produced by the battery bank. The input voltage is measured by the input voltage sense circuit 133,
206 which supplies a signal representative of the input voltage to the microcontroller 105 via path 143 for conversion
207 into digital form therein. The output voltage is measured by the output voltage sense circuit 135, which supplies
208 a signal representative of the output voltage to the microcontroller 105 via path 145 for conversion into digital
209 form therein. The output current is measured by the output current sense circuit 137, which supplies a signal
210 representative of the output current to the microcontroller via path 147 for conversion into digital form therein.
211 The battery current is measured either by an internal current sensing device such as a shunt resistor or hall
212 effect device, or alternatively by an external shunt at the battery bank (not shown), which supplies a signal
213 representative of the battery current to the microcontroller via connector 149 for conversion into digital form
214 therein.

215 The microcontroller 105 can also measure and/or maintain information regarding other characteristics of
216 the battery bank, such as temperature of the battery bank and the battery terminal voltage measured by
217 Kelvin connections. In the exemplary embodiment, a temperature sensor at the battery bank supplies a signal
218 representative of the battery bank temperature to the microcontroller 105 via connector 149 for conversion into
219 digital form therein. Similarly, a Kelvin connection at the battery bank supplies a signal representative of the
220 terminal voltage of the battery bank to the microcontroller 105 via connector 149 for conversion into digital
221 form therein. The Kelvin connection allows for more accurate monitoring of the terminal voltage of the battery
222 bank, especially during high current charging operations. In such high current charging operations, there can
223 be a significant voltage drop across the output of the converter, which causes the output voltage sense circuit
224 135 to underestimate of the true battery voltage. The Kelvin bridge circuit eliminates these inaccuracies as it
225 provides an accurate measurement of the terminal voltage of the battery bank during such high current charging
226 operations. The high accuracy battery voltage measurements are used in the preferred embodiment to provide
227 more accurate battery charging.

228 The microcontroller 105 also interfaces to a temperature sensor 153 internal to the system housing 101 to
229 measure the internal temperature of the system housing 101. This temperature can be used to activate, deactivate

230 and control the speed of a fan 155 that blows air from outside the system housing to the interior space of the
231 system housing for cooling as is well known. The microcontroller 105 can also interface to a temperature sensor
232 (not shown) to measure the temperature on the interior or of the heat sink. This temperature too can be used
233 to control the speed of the fan 155 (or additional fans) for cooling as needed.

234 The microprocessor 105 also interfaces to a front panel display and/or LED 157 and user input buttons 159
235 for presenting status information to the user as well as carrying out user interaction and control. The front
236 panel display and/or LED 157 preferably presents status indications of a multiplicity of parameters including PV
237 voltage, PV current, battery voltage, charging current, charging status, energy harvest history, battery energy
238 status, energy used, etc. microcontroller 105 regulates the output current by controlling the duty cycle of the
239 PMW control signals supplied to the gate drive circuitry 113A, 113B. The Bulk charging mode is used to charge
240 a battery that is in a relatively low charge state.

241 5 c) Absorption Charging Mode

242 In the absorption charging mode, the microcontroller 105 regulates the output voltage level (as measured by the
243 output voltage sense circuit 135 or by the Kelvin connection), such that it is maintained at a predetermined
244 absorption voltage level (referred to herein as Vabs). The predetermined absorption voltage level is preferably
245 a parameter that is set and possibly updated by user input; alternatively, it can be stored as a constant value.
246 The microcontroller 105 regulates the output voltage by controlling the duty cycle of the PMW control signals
247 supplied to the gate drive circuitry 113A, 113B. The Absorption charging mode is used to charge a battery at a
248 relatively high charge state.

249 6 d) Float Charging Mode

250 In the float charging mode, the microcontroller 105 regulates the output voltage level (as measured by the output
251 voltage sense circuit 135 or by the Kelvin connection), such that it is maintained at the predetermined float
252 voltage level (referred to herein a Vfloat). The predetermined float voltage level is preferably a parameter that is
253 set and possibly updated by user input; alternatively, it can be stored as a constant value. The microcontroller
254 105 regulates the output voltage by controlling the duty cycle of the PMW control signals supplied to the gate
255 drive circuitry 113A, 113B. The float charging mode is used to charge a battery at a full or substantially full
256 charge state e) MPPT Mode In the MPPT mode, the microcontroller 105 regulates the input voltage level such
257 that it is maintained at or near the peak power point on the current-voltage curve for the PV array 3 connected
258 thereto. This voltage level is referred to herein as "Vmpp". The microcontroller 105 regulates the input voltage
259 by controlling the duty cycle of the PMW control signals supplied to the gate drive circuitry 113A, 113B.

260 The automatic battery charging operations of FIGS. 3A and 3B are performed on a periodic basis, preferably
261 at least every 2 milliseconds or shorter. Such timing can be controlled by an interrupt timer or other timing
262 circuitry. The operations are carried out using a state variable "Mode" that is set to correspond to the given
263 operational mode, which can be either a predetermined value for the Off mode, a predetermined value for Bulk
264 Charging, a predetermined value for Absorption Charging or a predetermined value for Float Charging. Because
265 the MPPT mode can be used in conjunction with any one of the Bulk, Absorption and Float charging modes,
266 a status flag ("MPPT mode In the Off mode, the microcontroller 105 opens the output relays 119 such that no
267 current is passed through to the battery bank.

268 7 b) Bulk Charging Mode

269 In the bulk charging mode, the microcontroller 105 regulates the output current (as measured by the output
270 current sense circuit 137) such that it is at the maximum current limit of the converter (which is referred to
271 herein as I_{max} and is designed to prevent overload). The maximum current I_{max} is preferably a parameter that
272 is set and possibly updated by user input; alternatively, it can be stored as a constant value. The FLAG") is
273 also used. The MPPT mode flag is set to true when the MPPT mode is active and set to false when the MPPT
274 mode is inactive.

275 When the Mode variable is set, the microcontroller 105 automatically transitions to carry out the corresponding
276 control operations for the particular mode as described above. In the Off mode, the microcontroller 105 opens
277 the output relays 119 such that no current passes through from the input path 121 to the output path 123 and
278 to the battery bank. In the Bulk charging mode, the microcontroller 105 regulates the output current such that
279 it is at the maximum current limit I_{max}. In the Absorption charging mode, the microcontroller 105 regulates
280 the output voltage level such that it is maintained at a predetermined absorption voltage level Vabs. In the
281 Float charging mode, the microcontroller 105 regulates the output voltage level such that it is maintained at the
282 predetermined float voltage level Vfloat.

283 When the MPPT mode flag is set to true, the MPPT mode operations override the charging mode operations
284 (Bulk, Absorption or Float charging operations) as dictated by the Mode variable. Such override processing
285 causes the microcontroller 105 to regulate the input voltage level such that it is maintained at or near the V_{mpp}
286 value as described herein. When the MPPT mode flag is set to false, the override processing is avoided such that
287 the charging mode operations dictated by the Mode variable are performed.

7 B) BULK CHARGING MODE

288 The operations begin in step 302 where the microcontroller 105 uses the input voltage sense circuit 133 to
289 measure the input voltage (V_{in}), uses the output voltage sense circuit 135 to measure the output voltage (V_{out}),
290 and uses the output current sense circuit 137 to measure the output current (I_{out}). For reverse current protection,
291 the output relays 119 are switched OFF in the event that the output current I_{out} is less than a minimal threshold
292 current, for example 2 amperes. The output relays 119 are switched ON for power conversion in the Bulk
293 Charging, Absorption Charging, Float Charging and MPPT modes.

294 In step 304, the microcontroller 105 determines if the Mode variable is set to the "Off" value. If the
295 determination of step 304 is false, the operations continue to step 310. If the determination of step 304 is
296 true, the operations continue to step 306 where the microcontroller 105 checks whether the input voltage V_{in} is
297 less than the output voltage V_{out} . If the decision of step 306 is true, the microcontroller 105 in step 308 sets the
298 Mode variable to the "Bulk" value and the operations continue to step 344. If the decision of step 304 is false,
299 the microcontroller 105 continues to step 344.

300 In step 310, the microcontroller 105 determines if the Mode variable is set to the "Bulk" value. If the
301 determination of step 310 is false, the operations continue to step 320. If the determination of step 310 is true,
302 the operations continue to step 312 where the microcontroller 105 checks whether the input voltage V_{in} is less
303 than the maximum power point voltage V_{mpp} . If the decision of step 312 is true, the microcontroller 105 in
304 step 314 sets the MPPT Mode flag to true and the operations continue to step 344. If the decision of step 312 is
305 false, the microcontroller 105 continues to step 316 to check whether the output voltage V_{out} is greater than the
306 absorption voltage V_{abs} . If the decision of step 316 is true, the microcontroller 105 in step 318 sets the Mode
307 variable to the "Absorb" value and the operations continue to step 344. If the decision of step 316 is false, the
308 operations continue to step 344.

309 In step 320, the microcontroller 105 determines if the Mode variable is set to the "Absorb" value. If the
310 determination of step 320 is false, the operations continue to step 334. If the determination of step 320 is true,
311 the operations continue to step 322 where the microcontroller 105 checks whether the input voltage V_{in} is less
312 than the maximum power point voltage V_{mpp} . If the decision of step 322 is true, the microcontroller 105 in
313 step 324 sets the MPPT Mode flag to true and the operations continue to step 344. If the decision of step 322 is
314 false, the microcontroller 105 continues to step 326 to check whether the output current I_{out} is greater than the
315 maximum output current I_{max} . If the decision of step 326 is true, the microcontroller 105 in step 328 sets the
316 Mode variable to the "Bulk" value and the operations continue to step 344. If the decision of step 326 is false, the
317 operations continue to step 330 to check if an absorption timer has expired. The absorption timer is automatically
318 set when the microcontroller 105 transitions from the Bulk mode to the Absorption mode. The initial absorption
319 timer value is preferably a parameter that is set and possibly updated by user input; alternatively, it can be
320 stored as a constant value. If the test of step 330 is true, the microcontroller 105 in step 332 sets the Mode
321 variable to the "Float" value and the operations continue to step 344.

322 In step 334, the microcontroller 105 determines if the Mode variable is set to the "Float" value. If the
323 determination of step 334 is false, the operations continue to step 344. If the determination of step 334 is true,
324 the operations continue to step 336 where the microcontroller 105 checks whether the input voltage V_{in} is less
325 than the maximum power point voltage V_{mpp} . If the decision of step 336 is true, the microcontroller 105 in
326 step 338 sets the MPPT Mode flag to true and the operations continue to step 344. If the decision of step 336 is
327 false, the microcontroller 105 continues to step 346 to check whether the output current I_{out} is greater than the
328 maximum output current I_{max} . If the decision of step 346 is true, the microcontroller 105 in step 342 sets the
329 Mode variable to the "Bulk" value and the operations continue to step 344.

330 In step 344, the microcontroller 105 checks whether the MPPT status flag is set to true. If the test of step
331 344 fails, the operations end. If the test of step 344 is true, the operations continue in step 346 to check whether
332 the output current I_{out} is greater than the maximum output current I_{max} . If the decision of step 346 is true,
333 the microcontroller 105 in step 348 sets the Mode variable to the "Bulk" value and clears the MPPT Mode flag
334 to false and the operations end. If the decision of step 346 is false, the operations continue to step 350.

335 In step 350, the microcontroller 105 checks whether the Mode variable is set to the "Absorb" value. If the
336 test of step 350 is false, the operations continue to step 360. If the test of step 350 is true, the microcontroller
337 105 continues to step 352 to check whether the output voltage is greater than the V_{abs} . If so, the operations
338 continue to step 354 to set the Mode variable to the "Absorb" value and clears the MPPT Mode flag to false and
339 the operations end. If not, the operations end.

340 In step 360, the microcontroller 105 checks whether the Mode variable is set to the "Float" value. If the test
341 of step 360 is false, the operations continue to step 366. If the test of step 360 is true, the microcontroller 105
342 continues to step 362 to check whether the output voltage is greater than V_{float} . If so, the operations continue to
343 step 364 to set the Mode variable to the "Float" value and clears the MPPT Mode flag to false and the operations
344 end. If not, the operations end.

345 In step 366, the microcontroller 105 checks whether the input voltage is greater than the output voltage. If
346 so, the Mode variable is set to the "Off" value and clears the MPPT Mode flag to false and the operations end.
347 If not, the operations end.

348 In each one of the Bulk Charging Mode, Absorption Charging Mode and the Float Charging mode, the PV
349 array may not be able to supply the required power to achieve the desired voltage or current limits set by
350 the charging operations. Under these conditions, the microcontroller 105 transitions to the MPPT mode. For

351 example, for the Bulk Charging Mode, the microcontroller 105 automatically transitions to the MPPT mode in
352 steps 312 and 314. In the Absorption Charging Mode, the microcontroller 105 automatically transitions to the
353 MPPT mode in steps 322 and 324. In the Float Charging Mode, the microcontroller 105 automatically transitions
354 to the MPPT mode in steps 336 and 338.

355 For the MPPT mode, the microcontroller 105 regulates the input voltage level such that it is maintained
356 at or near the peak power point on the current-voltage curve for the PV array as shown graphically in FIG.
357 ??A. This voltage level is referred to herein as "V_{mpp}". In the preferred embodiment, the V_{mpp} voltage level
358 is derived from a scanning step as well as perturbation and observation steps. The scanning step is graphically
359 illustrated in FIG. ??B In alternative embodiments, it is contemplated that the scanning operations can start at
360 the bottom of the range and sweep the input voltage by ramping up the input voltage. At the top of the range,
361 the microcontroller can then ramp down the input voltage to the V_{mpp} voltage level.

362 In the illustrative embodiment, the perturbation and observation steps include the following sequence of
363 operations: i) the output current is measured a number of times (for example, 128 times in one embodiment) to
364 reduce any inaccuracies due to noise and the average is stored as the maximum current point ??C); and vi) The
365 stored output current values for the steps i)-v) above are processed to select the highest output current value and
366 the voltage value for that selected sample point is stored as the new V_{mpp} value. Note that for the perturbation
367 and observation step described above, the number of sample points, the voltage difference between the sample
368 points, and the order in which the sample points are measured can be changed as desired and are proved for
369 illustrative purposes.

370 Also note that for the perturbation and observation step described above, one of the sample points is the V_{mpp}
371 point itself, multiple sample points are provided at voltage levels above the V_{mpp} point, and multiple sample
372 points are provided at voltage levels below the V_{mpp} point. Such sampling quickly locates the maximum power
373 point and thus reduces the processing time and delays associated therewith. Such reduction in processing time
374 improves the efficiency of the power conversion process, especially in dynamic conditions (e.g., changing sunlight
375 due to moving cloud cover and the like).

376 FIG. ?? is a flow chart illustrating exemplary control operations that are carried out by the microcontroller 105
377 in order to calculate and update the V_{mpp} value as described herein. Such operations are preferably performed
378 on a periodic basis when the MPPT mode flag is activated in accordance with the operations of FIG. ?? as
379 described above. Such timing can be controlled by an interrupt timer or other timing circuitry. In the illustrative
380 embodiment, the operations of FIG. ?? are performed on a period basis every 2 milliseconds or shorter, which
381 corresponds to a frequency of 500 Hz or greater. In this manner, the V_{mpp} values are updated at least every
382 2 milliseconds or less (or at a frequency of 500 Hz or greater), which enhances the efficiency of the conversion
383 process especially during dynamic conditions.

384 In step 501, the microcontroller 105 checks whether the V_{mpp} has been initialized. If no, the microcontroller
385 105 performs as initial scanning step as described above with respect to FIG. ??B. This scanning step calculates
386 the initial V_{mpp} value for the MPPT mode processing.

387 In step 503, the microcontroller 105 checks whether the input voltage V_{in} is within a predetermined voltage
388 range (for example between 50% V_{oc} and 90% V_{oc}. If not, the operations continue to step 505 to perform a
389 scanning step as described above with respect to FIG. ??B If the results of step 503 indicate that the input voltage
390 V_{in} is within the predetermined voltage range, the operations continue to step 507 to perform a perturbation
391 and observation step as described above with respect to FIG. ??C. The perturbation and observation of step 507
392 updates the V_{mpp} value. From step 507, the operations end.

393 There have been described and illustrated herein an embodiment of charge controller for solar applications
394 and methods of operating same. While a particular embodiment of the invention have been described, it is not
395 intended that the invention be limited thereto, as it is intended that the invention be as broad in scope as the
396 art will allow and that the specification be read likewise. Thus, while particular control operations (including
397 particular control states and transitions between control states) have been disclosed, it will be appreciated that
398 other control operations can be used as well. In addition, while particular buck-type converter topologies have
399 been disclosed, it will be understood that the general control operations described herein can be used with other
400 PWMcontrolled converter topologies or other non-PWM converter topologies. Also, while it is preferred that the
401 control operations of the charge controller be carried out by a microcontroller element, it will be recognized that
402 other control elements and control systems can be used (such as a microprocessor, a digital signal processor, an
403 ASIC, a CPLD, an FPGA, or other digital logic device).

404 8 VI.

405 9 Conclusion

406 It is preferably that the control operations be realized as a program of instructions that are loaded into the
407 firmware of the microcontroller or other programmed logic device. Furthermore, while the embodiments described
408 above utilize field effect transistors as switching devices, it will be understood that other switching devices such as
409 IGBT insulated gate bipolar transistors can be similarly used. In addition, while particular solar applications have
410 been disclosed, it will be understood that the charge controller described herein can be adapted for other energy
411 conversion applications such as wind energy harvesting, waveenergy harvesting, hydroelectric energy harvesting,

412 thermoelectric energy harvesting, etc. It will therefore be appreciated by those skilled in the art that yet other
413 modifications could be made to the provided invention without deviating from its spirit and scope as claimed.



Figure 1: Fig. 1 :

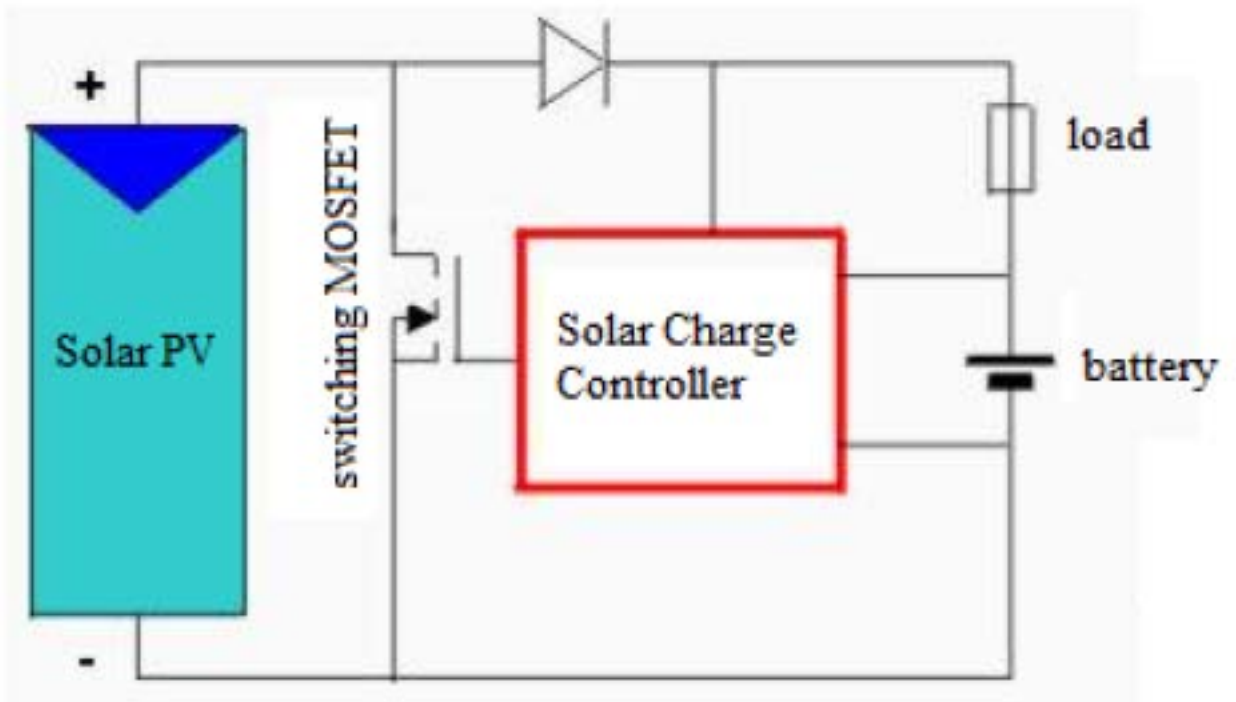
413 1 2 3 4
414

¹F © 2016 Global Journals Inc. (US) Maximum Power Point charge Controller for DC-DC Power Conversion in Solar PV System

²© 2016 Global Journals Inc. (US)

³Maximum Power Point charge Controller for DC-DC Power Conversion in Solar PV System

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25

Figure 2: Fig. 2 :FFFig. 5 :

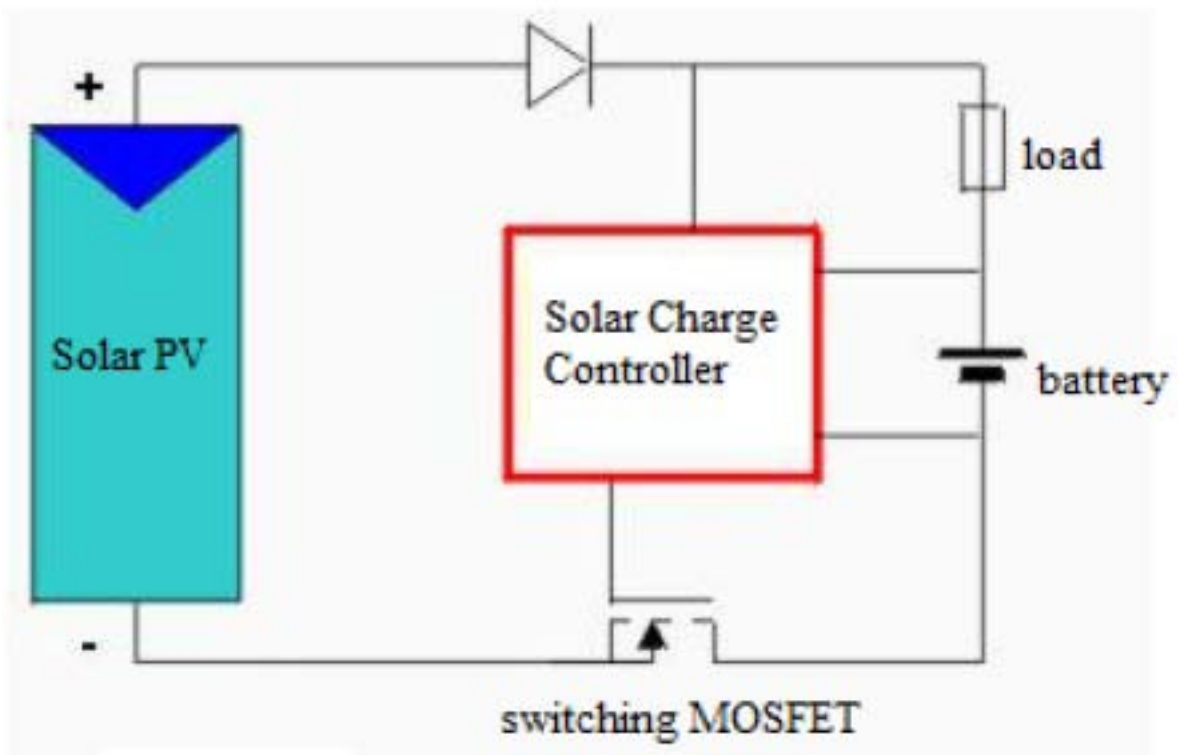
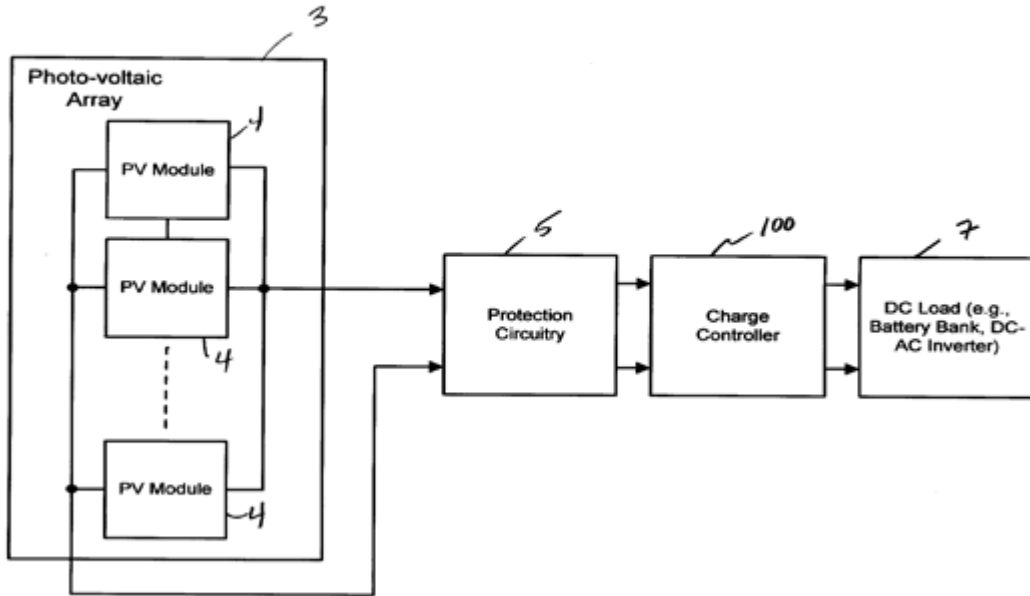


Figure 3:



Figure 4:

FIG. 1



2016

Figure 5: 2016 F©

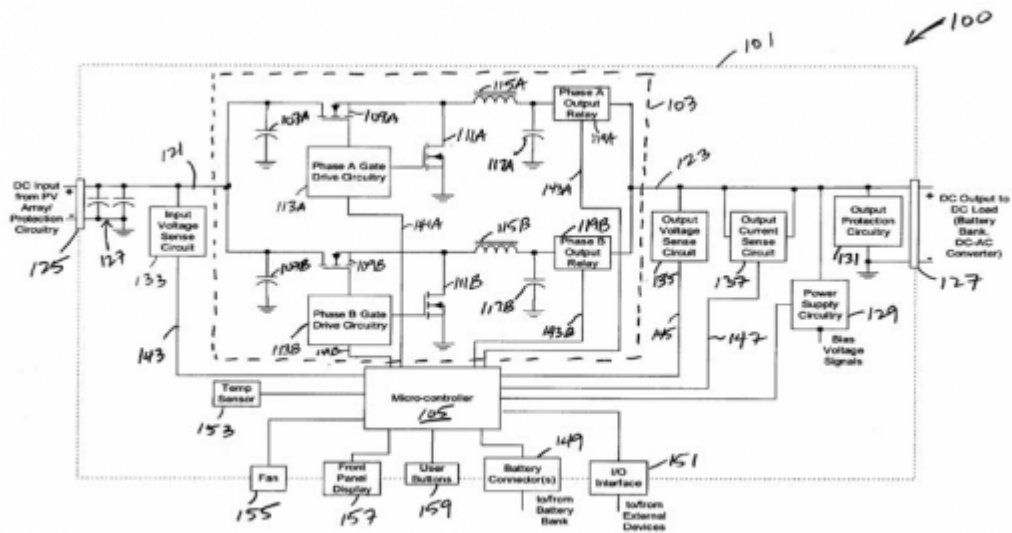


Figure 6:

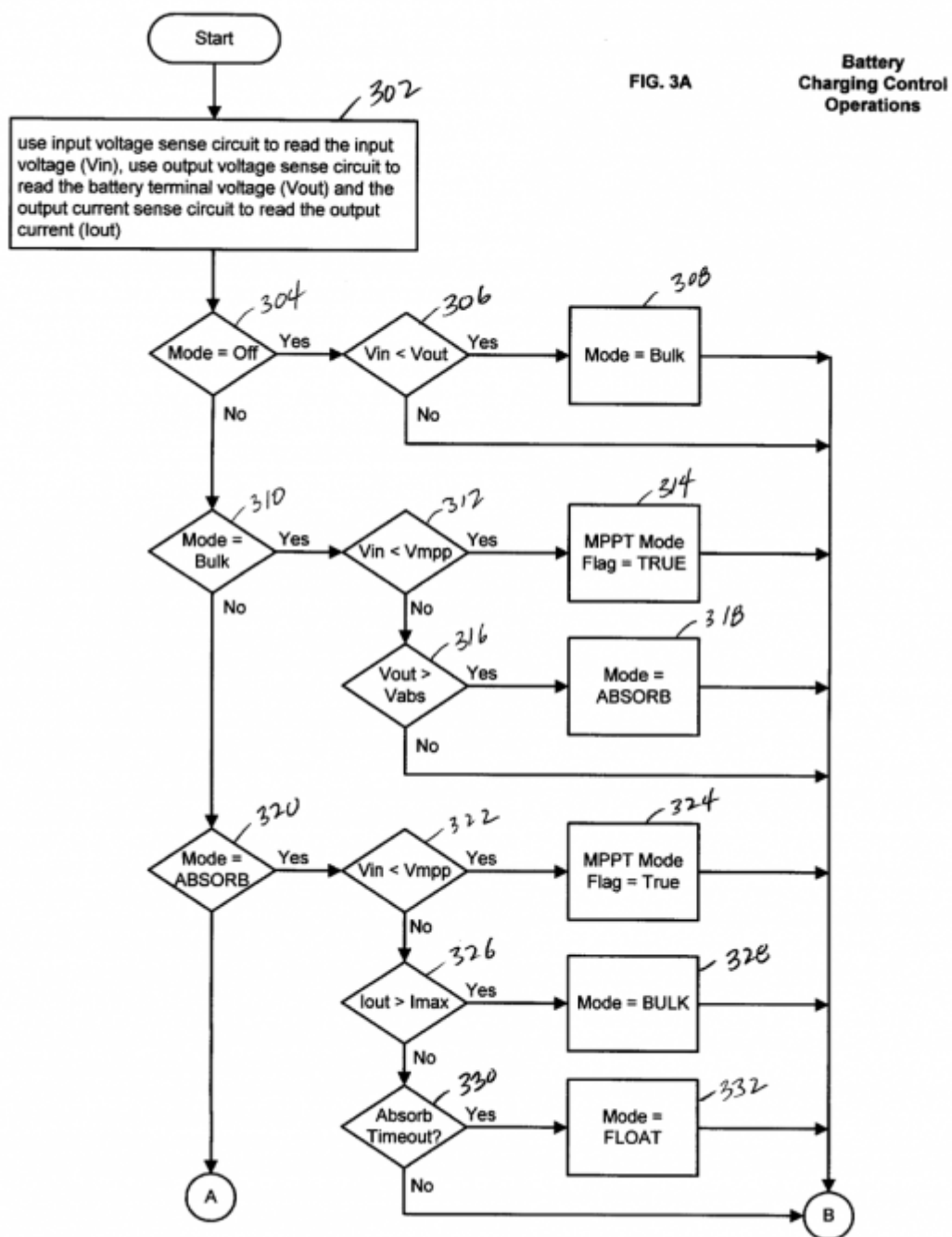


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