REPLY TO
ATTN OF: GP

TO: XXX/Scientific & Technical Information Division
    Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
      Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,600,599
Government or Corporate Employee : TRW Inc.
Supplementary Corporate Source (if applicable) : Redondo Beach, CA.
NASA Patent Case No. : GSC-10,135

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES □ NO □

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Henderson

Enclosure

(NASA-Case-GSC-10135) SHUNT REGULATION ELECTRIC POWER SYSTEM Patent (NASA) 9 P CSCL 09C

Unclas

00/33 05418
ABSTRACT: A regulated electric power system having load and return bus lines. A plurality of solar cells interconnected in power supplying relationship and having a power shunt tap point electrically spaced from the bus lines is provided. A power dissipator is connected to the shunt tap point and provides for a controllable dissipation of excess energy supplied by the solar cells. A dissipation driver is coupled to the power dissipator and controls its conductance and dissipation and is also connected to the solar cells in a power taping relationship to derive operating power therefrom. An error signal generator provides an error output signal which is representative of the difference between the electric parameters existing at the load bus and the reference signal generator. An error amplifier is coupled to the error signal generator and the dissipation driver to provide the driver with controlling signals.
PATENTED AUG 17 1971

SHEET 2 OF 4

Fig. 3A

$V_L = V_1 + V_2$

Fig. 3B

$P_{gh} = I_S V_1$

Fig. 4

Warren H. Wright
John J. Biess
INVENTORS

BY

Attorney
Fig. 7

Fig. 8

Fig. 9

Warren H. Wright  
John J. Biess  
INVENTORS

BY

Warrent F. Anderson
ATTORNEY
SHUNT REGULATION ELECTRIC POWER SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to electric power supply systems and more particularly to electrical regulation thereof vis-a-vis effectively nonconstant source elements and/or varying conditions of energy storage and load utilization.

Although the invention finds particularly advantageous application in the field of multielement arrays of solar cell power supplies coupled to storage batteries for powering equipment and instrumentation remote from conventional power sources e.g. space satellite applications, and although in the cause of brevity and clarity of presentation much of the following discussion and description of examples of the invention relate particularly thereto, it is expressly to be understood that the advantages of the invention are equally well manifest in other fields of electric energy supply such as, for example, the utilization of thermoelectrics, fuel cells, and the like where load conditions and source output capacity may widely vary as in a cyclic or lifetime degrade manner.

1. FIELD OF THE INVENTION

Prior art approaches to the problems enumerated have typically been directed toward providing series regulator apparatus connected in series between the source panel and its load. The regulation is achieved by blocking and dissipating excess power from the array whereby a predetermined load bus voltage or current is maintained. The disadvantages of such series dissipative regulators result from the design of the regulator to conduct the full load current which mandates a large dissipative capability particularly, for example, during post eclipse portions of the cycle when the storage batteries are typically demanding maximum charge current and the array, although illuminated, is still cold. In addition, the series arrangement generally requires considerable drive power and causes appreciable loss of array power when no dissipation is required or desired as during periods of partial eclipse or at the times approaching system end of life. These difficulties of series regulation can be obviated by complex bypassing and switching circuitry or by adding compensating additional transducer cells to the array. Either solution, however, constitutes a cost disadvantage in adding weight and complexity and adds to system failure probability.

Prior art shunt regulation techniques have heretofore typically been directed toward providing apparatus which achieves dissipation of excess array power in a substantially brute-force manner. Again, unless complex circuitry is utilized, the minimum standby power for control and drive of the

circuitry which desirably, is to be dissipated. The combination of this example includes novel redundantly reliable configurations in the power dissipation components and minor loop feedback stabilization configurations in the low-power control network portions.

Further details of these and other novel features and their principles of operation as well as additional objects and advantages of the invention will become apparent and be best understood from a consideration of the following description when taken in connection with the accompanying drawings which are all presented by way of illustrative example only.
BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an overall block diagram view of an example of an electric power regulation system constructed in accordance with the principles of the present invention;

FIG. 2A is a schematic diagram of a portion of an analogous system as provided according to a typical prior art approach;

FIG. 2B is a graph plotting array current on the ordinate as a function of array voltage on the abscissa for the prior art structure of FIG. 2A;

FIG. 3A is a schematic diagram of a portion of a simplified example of the structure of FIG. 1;

FIG. 3B is a pair of graphs, each similar to that of FIG. 2B, relating to the operation of the structure of FIG. 3A;

FIG. 4 is a schematic diagram of a detail portion of an example of the structure of FIG. 1;

FIG. 5 is a schematic diagram of structure alternative to that of FIG. 4;

FIG. 6 is a schematic diagram of a detail portion of an example of the structure of FIG. 1;

FIG. 7 is a detail block diagram of a portion of an example of the structure of FIG. 1;

FIG. 8 is a schematic diagram of an example of a typical power dissipation amplifier 44 driven by the error signal controlled driver 38 intercoupled between the shunt power tap 42 and the return bus 22 in a manner to reduce the array output, in accordance with its overall current voltage characteristic, thereby to control the monitored power source parameter.

Referring to FIG. 2A, a prior art shunt regulator is indicated and includes a power transistor 46 coupled in shunt across the entire array 48. The total array current is designated I, the load bus current and voltage as I, V, respectively, and the shunted, dissipated current as I.

The output characteristic is displayed in FIG. 2B wherein I, is plotted as a function of the array voltage. Assuming a desired load current I, and a desired load voltage V,, the array being operated at the point 50 on the array characteristic curve 52, it may be seen that the difference I, - I, is the current to be shunted thereby to dissipate the power that results from the shaded area on the graph and must be dissipated by the transistor 46. The power to be delivered to the load is the larger, unshaded, rectangular area below the shaded rectangle.

In FIG. 3A a portion of an example of the high efficiency shunt regulator of the present invention is illustrated and includes a series string of photovoltaic transducers 54, 56 connected between a load bus 58 and a return 60. The dissipative shunt circuit is shown connected between a shunt power tap 62 and the return bus. The shunt circuit comprises a passive dissipative portion indicated by the device 64 and a power transistor 66. The total array voltage is V, and is the sum of the tap-to-bus voltages V, V, I, is load bus current and I, is the effective shunt loop current.

Referring to FIG. 3B, the total or overall array characteristic is shown resolved into two component characteristics each related to a respective set V, and I, as illustrated by the curves 68, 70 respectively. (It should be noted that the curves 52, 68, and 70 are drawn to approximately the same scale).

Assuming again that I, is the desired output current and V, is the desired output voltage, the upper element 54 may be operated at the point 72 on the curve 70 thus providing a voltage V,. The element 56 in order to operate at the desired voltage V, is then controlled to operate at the point 74 on the characteristic 68. Operation at the point 74, however, is seen to require shunting of the current I, being again the difference between I, and I,. As they relate to the curve 68 the consequent dissipation, however, is only of the power represented by the area V, I, on the curve 68. In this particular illustration, the power to be dissipated is due to the composite characteristic of the elements 54, 56, and is of the order of half that for the prior art full shunt case. The dissipation in the amplifier element 66 is further reduced by the passive dissipator resistor 64. Thusly the current and thermal stresses on the dissipative components is greatly reduced resulting in their increased lifetimes and permitting the design deletion of much thermal energy transfer apparatus for removing heat from the dissipative elements.

In FIG. 4 an array 76 of photovoltaic transducer elements is illustrated in which a number of electrically similar shunt tap power points 78, 80 are shown to each of which is connected a controlled dissipative shunt element 82, 84, respectively. In FIG. 5, the tap points 78', 80' are shown electrically connected and with the dissipative elements 82', 84' connected directly in parallel. Again passive dissipative elements may be incorporated to increase further the system reliability and decrease the active element thermal stresses.

The error signal output from the generator circuit 32 is impressed upon an error signal amplifier 36 which, in turn, supplies a control signal for a driver amplifier 38. The driver 75 draws operating power from the array 10 at a source tap 40 which is electrically interposed between a shunt power tap 42 and the load bus 29. It may be noted that in accordance with the present invention, the driver power tap may be electrically any selected array point between and including the shunt power tap 42 and a point significantly different from the bus 20; the criteria for such selection being discussed infra.

In FIG. 1 a solar array power supply system is illustrated which includes a network 10 of source elements 12, 14, 16, 18. The elements in this example are individual photovoltaic cells arranged in a matrix configuration including at least one string of series connected elements connected between load and return buses 20, 22, respectively. The figure is generalized to indicate that different numbers of strings and strings of different element quantities may be utilized.

A storage battery 24 and a load circuit 26 are shown coupled to the source buses by means of a charge-discharge control network 28 which, by substantially conventional techniques, channels electrical power into the battery from the solar cell array for charging, out of the battery and to the load, or directly from the source to the load depending upon the instantaneous load requirements, the state of charge of the battery, and the output available from the solar cell array.

Interposed between the array 10 and the utilization components 24, 26, 28 is a shunt regulator system 30. In this example, an error signal generator 32 compares an electrical parameter associated with the load bus 20 with a parameter value reference or standard 34 and generates an error signal representative of their difference. In the example illustrated, the control parameter is the load bus voltage; however, clearly, other parameters such as load bus current, battery current, output power, or the like may, as desired, be utilized as the quantity to be monitored and controlled.

The error signal output from the generator circuit 32 is impressed upon an error signal amplifier 36 which, in turn, supplies a control signal for a driver amplifier 38. The driver 75...
Referring to FIG. 6, a further example of increased dissipation capacity and reliability is illustrated. An array 86 is shown having a power shunt tap at the point 88 to which is coupled a series quad amplifier arrangement 90 of power transistors 92, 94, 96, 98. The quad configuration is common-base driven from a driver current control circuit 100 controlled in turn by a signal from the error amplifier, not shown, and deriving its operating power from the array at the reduced voltage (with respect to the load bus voltage) point 102. During normal mode operation, the dissipation of the energy associated with ZM drawn from the tap 88, is equally shared by the two quad-amplifier transistors 92, 96. When, however, any one of the transistors fails in either open or shorted mode, the amplifier continues to operate.

The example of FIG. 6 further illustrates the reduced minimum power drain and dissipation of the driver circuit from the source array 86. Assuming that a given driver current is required at the base bus 104, the power dissipated by the driver 100 is, to at least a good approximation, the product IcVc where Vc is the voltage across the driver circuit as indicated. Conventionally, Ic is drawn from the load bus thusly maximizing the energy required. By the present invention the power for the driver being taken from a reduced voltage point 102 significantly reduces the maximum power drain caused by the driver apparatus.

An example of the error amplifier stability and reliability configuration of the invention is illustrated in FIG. 7. The error amplifier is seen to include three stages 106, 108, 110 coupled in a cascade relation between the error signal generator 32 and the driver network 38. When it is assumed that the gain A1, A2, A3 of each stage could vary by, say, a factor of 2, then the overall amplifier variation could be a factor of 8. The minor loop feedback combination indicated, which includes a respective feedback proportion H1, H2, H3 gain = A1A2A3 where A1=A1/(1+H1A1) and can be well approximated as A1' =1/H1 when A1H1>>1. Accordingly the total gain variation can be realistically very small since the total gain = 1/(H1H2H3) and each of the feedback loops may consist of passive, drift free components.

Current amplifier stages may, as desired, similarly combine gain stabilization as shown in the illustration of FIG. 8. The current gain of the typical stage 112 is stabilized by combination of selected base and emitter resistors. The stabilizing selection may be made in a manner to satisfy the relation Ic/Ic' = (Rb/Rb') wherein Ic and Ic' are collector and base current magnitudes, respectively, and Rb and Rb' are the ohmic values of the base and emitter resistors, respectively.

Referring to FIG. 9 as Majority Voting AND Gate example of the 1x4 illustrated as a combination with three redundant amplifiers 116, 118 each intrinsically stabilized as indicated and each fed by a separate, redundant error signal generator 120, 122, 124 and associated reference. Where the output signal of each error amplifier is V1, V2, V3, respectively, they are coupled to the six element Majority Voting AND Gate amplifier as shown to provide the output error signal, to the driver, V0 = (V1V2V3) + (V1V2V3) + (V1V2V3) where in the dot "and" and the plus operator is defined as "or." Accordingly, it is clear by inspection that V0 is highly stable with respect to the "error" associated with the load bus irrespective of any failures in a reference, amplifier, feedback, or gate element.

There have thus been disclosed and described a number of examples and novel structural aspects of an electric power regulation system which achieves the objects and exhibits the advantages set forth above.

We claim:

1. A regulated electric power system comprising:
load and return bus means;

2. A regulated electric power system comprising:

3. A regulated electric power system comprising:

4. A regulated electric power system comprising:

5. A regulated electric power system comprising:

6. A regulated electric power system comprising:

7. A regulated electric power system comprising:

8. A regulated electric power system comprising:

9. A regulated electric power system comprising:

10. A regulated electric power system comprising:

11. A regulated electric power system comprising:

12. A regulated electric power system comprising:

13. A regulated electric power system comprising:

14. A regulated electric power system comprising:

15. A regulated electric power system comprising:

16. A regulated electric power system comprising:

17. A regulated electric power system comprising:

18. A regulated electric power system comprising:

19. A regulated electric power system comprising:

20. A regulated electric power system comprising:

21. A regulated electric power system comprising:

22. A regulated electric power system comprising:

23. A regulated electric power system comprising:

24. A regulated electric power system comprising:

25. A regulated electric power system comprising:

26. A regulated electric power system comprising:

27. A regulated electric power system comprising:

28. A regulated electric power system comprising:

29. A regulated electric power system comprising:

30. A regulated electric power system comprising:

31. A regulated electric power system comprising:

32. A regulated electric power system comprising:

33. A regulated electric power system comprising:

34. A regulated electric power system comprising:

35. A regulated electric power system comprising:

36. A regulated electric power system comprising:

37. A regulated electric power system comprising:

38. A regulated electric power system comprising:

39. A regulated electric power system comprising:

40. A regulated electric power system comprising:

41. A regulated electric power system comprising:

42. A regulated electric power system comprising:

43. A regulated electric power system comprising:

44. A regulated electric power system comprising:

45. A regulated electric power system comprising:

46. A regulated electric power system comprising:

47. A regulated electric power system comprising:

48. A regulated electric power system comprising:

49. A regulated electric power system comprising:

50. A regulated electric power system comprising:

51. A regulated electric power system comprising:

52. A regulated electric power system comprising:

53. A regulated electric power system comprising:

54. A regulated electric power system comprising:

55. A regulated electric power system comprising:

56. A regulated electric power system comprising:

57. A regulated electric power system comprising:

58. A regulated electric power system comprising:

59. A regulated electric power system comprising:

60. A regulated electric power system comprising: