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(54) Title: SYSTEMS AND METHODS FOR IDENTIFYING ANOMALOUS EVENTS FOR ELECTRICAL SYSTEMS

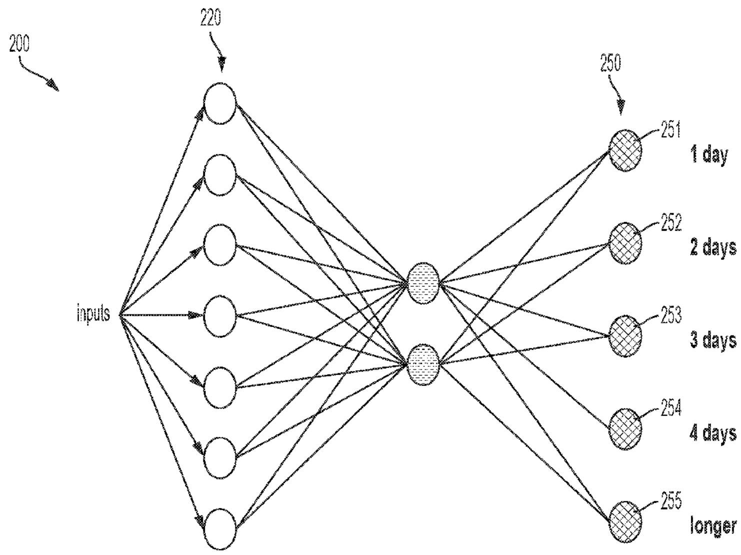

FIG. 2

(57) Abstract: The present disclosure relates to systems and methods for identifying anomalous events. In at least one illustrative embodiment, a method may comprise segmenting live time series data representing one or more characteristics of an electrical system into a plurality of live data segments, and inputting one or more of the plurality of live data segments to a trained neural network to output a predicted time-to-event parameter for each inputted data segment, the predicted time-to-event parameter representing a predicted amount of time between the data in the inputted data segment and a predicted anomalous event associated with the electrical system. The neural network may be trained using a plurality of historical data segments each having an assigned time-to-event parameter, each assigned time-to-event parameter representing an amount of time between the data in the corresponding data segment and a histroical anomalous event associated with the electrical system.

WO 2020/010291 A1

[Continued on next page]

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(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)* **:** ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, Cl, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

SYSTEMS AND METHODS FOR IDENTIFYING ANOMALOUS EVENTS FOR ELECTRICAL SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of and priority to U.S. Provisional Patent Application No. 62/694,432, filed July 5, 2018, the entire disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to systems and methods for identifying and reporting potential upcoming anomalous events for an electrical system.

BACKGROUND

[0003] Photovoltaic (PV) solar plants are susceptible to interruptions caused by, for example, overheating, broken equipment, or a decrease in the amount of sunlight available. These events must be rectified or compensated for so that the plant can meet its obligations to consumers and/or government regulators. Other electrical systems suffer from similar anomalous events that can cause disruptions in service.

[0004] Most events do not spontaneously appear but, instead, are the result of degradation over time or are part of some pattern. These patterns are usually difficult to notice. As a result, most problems only become apparent to the operator after a device fails to perform as expected.

SUMMARY

[0005] According to one aspect of the present disclosure, a method may comprise segmenting first time series data representing one or more characteristics of an electrical system into a first plurality of data segments, assigning a time-to-event parameter to each of the first plurality of data segments, each time-to-event parameter representing an amount of time between the data in the corresponding data segment and an anomalous event associated with the electrical system, and training a neural network using the first plurality of data segments together with the assigned time-to-event parameters.

[0006] In some embodiments, the first time series data may be generated by one or more sensors measuring the one or more characteristics of the electrical system.

[0007] In some embodiments, the first time series data may be collected from at least one of a solar panel array and a direct current to alternating current inverter.

[0008] In some embodiments, the method may further comprise segmenting second time series data representing the one or more characteristics of the electrical system into a second plurality of data segments, and inputting one or more of the second plurality of data segments to the trained neural network to output a predicted time-to-event parameter for each inputted data segment, the predicted time-to-event parameter representing a predicted amount of time between the data in the inputted data segment and a predicted anomalous event associated with the electrical system.

[0009] In some embodiments, the second time series data may represent the one or more characteristics of the electrical system during a later time period than the first time series data.

[0010] In some embodiments, each of the second plurality of data segments may be input to the trained neural network in real time as the second time series data is collected and segmented.

[0011] In some embodiments, the first time series data and the second time series data may each be collected from at least one of a solar panel array and a direct current to alternating current inverter.

[0012] In some embodiments, the electrical system may be a solar power plant or a subsystem thereof.

[0013] In some embodiments, the anomalous event may correspond with overheating of the electrical system.

[0014] In some embodiments, the anomalous event may correspond with a decrease in available sunlight.

[0015] In some embodiments, the anomalous event may correspond to a reduction in power generation by the solar power plant.

[0016] In some embodiments, the anomalous event may correspond to a disruption in service of the electrical system.

[0017] In some embodiments, the electrical system may consist of a single electrical device.

[0018] In some embodiments, the electrical system may comprise a collection of multiple electrical devices.

[0019] According to another aspect of the present disclosure, a method may comprise segmenting live time series data representing one or more characteristics of an electrical system into a plurality of live data segments, and inputting one or more of the plurality of live data segments to a trained neural network to output a predicted time-to-event parameter for each inputted data segment, the predicted time-to-event parameter representing a predicted amount of time between the data in the inputted data segment and a predicted anomalous event associated with the electrical system, where the trained neural network was previously trained using a plurality of historical data segments each having an assigned time-to-event parameter, the plurality of historical data segments being generated from historical time series data representing the one or more characteristics of the electrical system, each assigned time-to-event parameter representing an amount of time between the data in the corresponding data segment and a historical anomalous event associated with the electrical system.

[0020] In some embodiments, the time series data may be generated by one or more sensors measuring the one or more characteristics of the electrical system.

[0021] In some embodiments, first time series data may be collected from at least one of a solar panel array and a direct current to alternating current inverter.

[0022] In some embodiments, the electrical system may be a solar power plant or a subsystem thereof.

[0023] In some embodiments, the anomalous event may correspond with overheating of the electrical system.

[0024] In some embodiments, the anomalous event may correspond with a decrease in available sunlight.

[0025] In some embodiments, the anomalous event may correspond to a reduction in power generation by the solar power plant.

[0026] In some embodiments, the anomalous event corresponds to a disruption in service of the electrical system.

[0027] In some embodiments, the electrical system may consist of a single electrical device.

[0028] In some embodiments, the electrical system may comprise a collection of multiple electrical devices.

[0029] According to still another aspect of the present disclosure, one or more computer-readable media may store a plurality of instructions that, when executed by a power controller operatively connected to (i) at least one solar panel array and (ii) an inverter electrically coupled to the at least one solar panel array, cause the power controller to perform any of the methods described above and throughout this disclosure.

[0030] According to yet another aspect of the present disclosure, a power controller may be configured to perform any of the methods described above and throughout this disclosure.

In some embodiments, the power controller may be operatively connected to (i) at least one solar panel array and (ii) an inverter electrically coupled to the at least one solar panel array. In some embodiments, the power controller, the at least one solar panel array, and the inverter may be incorporated in a power plant.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The concepts described in the present disclosure are illustrated by way of example and not by way of limitation in the accompanying figures. For simplicity and clarity of illustration, elements illustrated in the figures are not necessarily drawn to scale. For example, the dimensions of some elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference labels have been repeated among the figures to indicate corresponding or analogous elements. The detailed description particularly refers to the accompanying figures in which:

[0032] FIG. 1 is a simplified block diagram illustrating an exemplary layout for a solar plant utilizing event prediction to detect potential losses in power generation;

[0033] FIG. 2 is a simplified diagram illustrating one possible embodiment of the architecture of the presently disclosed neural network; and

[0034] FIG. 3 is a simplified graph illustrating one example of data to be input into the presently disclosed neural network.

DETAILED DESCRIPTION OF THE DRAWINGS

[0035] While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the figures and will be described herein in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives consistent with the present disclosure and the appended claims.

[0036] References in the specification to “one embodiment,” “an embodiment,” “an illustrative embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may or may not necessarily include that particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0037] The disclosed embodiments may be implemented, in some cases, in hardware, firmware, software, or any combination thereof. The disclosed embodiments may also be implemented as instructions carried by or stored on a transitory or non-transitory computer-readable storage medium, which may be read and executed by one or more processors. A computer-readable storage medium may be embodied as any storage device, mechanism, or other physical structure for storing or transmitting information in a form readable by a computing device (e.g., a volatile or non-volatile memory, a media disc, or other media device).

[0038] In the drawings, some structural or method features may be shown in specific arrangements and/or orderings. However, it should be appreciated that such specific arrangements and/or orderings may not be required. Rather, in some embodiments, such features may be arranged in a different manner and/or order than shown in the illustrative figures. Additionally, the inclusion of a structural or method feature in a particular figure is not meant to imply that such feature is required in all embodiments and, in some embodiments, may not be included or may be combined with other features.

[0039] The presently disclosed systems and methods operate using segmented time series data, collected from an electrical system (which may be a single electrical device or a collection of multiple electrical devices), with a neural network 200 designed to predict a future anomalous event affecting the electrical system and the amount of time before said event. In particular, the neural network 200 receives segmented time series data representing any number of characteristics of the electrical system, which may be naturally occurring and/or controlled by the operator, and predicts anomalous events which could result in a reduction or cessation of power generation or transmission if not addressed. Each segment of time series data input to the neural network is assigned a time-to-event parameter, which represents the amount of time between the data and a known anomalous event (for data used in training the neural network 200) or the amount of time until a predicted anomalous event is likely to occur (for live data input to the neural network 200 for analysis).

[0040] FIG. 1 illustrates, in a simplified block diagram, a simplified layout 100 of a power plant 102 that uses the event prediction methods described herein. The power plant 102 includes a power controller 120 that is operatively connected to one or more solar panel arrays 130 via a direct current (DC) to alternating current (AC) (DAC) inverter 140. The power controller 120 is further communicatively coupled to a system operator 104 and is configured to dynamically control performance of the DAC inverter 140. The DAC inverter 140 is used in solar power generation and may be programmed to provide ancillary services, such as, for example, voltage and frequency regulation, power factor correction, and reactive power control. Such a DAC inverter 140 may stabilize the power system 100 and compensate rapid fluctuations in supply and demand that result from intermittent renewable resources. It should be appreciated that, in some embodiments, the power controller 120 may be embodied as part of DAC inverter 140.

[0041] The neural network 200 may be a component of the power controller 120, a component of the DAC inverter 140, or external to the power plant 102 and accessible through a network 106. Time series data may be collected from the solar panel array 130, the DAC inverter 140, the power controller 120, the system operator 104, and/or other components of the system 100 and sent to the neural network 200 for processing. It is contemplated that time series data representing any number of characteristics associated with the electrical system being characterized may be used as inputs to the neural network 200.

[0042] FIG. 2 illustrates a simplified diagram of one embodiment of the neural network 200 for predicting if and when an anomalous event is likely to occur. It should be appreciated that, in some embodiments, a different number of inputs 220 and/or a different number of outputs 250 may be present depending on the exact specifications of the system and the need of the user.

[0043] In the illustrative embodiment, the inputs 220 to the neural network 200 are segments of time series data collected from or by the components in FIG. 1. This data can represent natural phenomenon and/or inputs controlled by the user. The outputs of the neural network 200 are time-to-event parameters. In this example, an output field 251 is labelled “1 day”, output field 252 is labeled “2 days,” output field 253 is labeled “3 days,” output field 254 is labeled “4 days,” and output field 255 is labeled “longer.” It is contemplated that other embodiments of the neural network 200 may use different numbers of outputs and/or different time scales. For instance, in other embodiments, the outputs 250 may represent time periods of seconds, minutes, hours, months, years, etc. The time values associated with output field and the number of output fields may change depending on the application and/or the needs of the user.

[0044] Referring now to FIG. 3, a simplified graph is shown with time series data representing a characteristic of the DAC inverter 140 before an anomalous event. The x-axis of the graph represents the amount of time before the event, and the event occurs on the left side of the graph where x=0. This means that time flows from right to left on the x-axis, as the rightmost part of the graph represents the greatest amount of time before the event. The y-axis of the graph is the value of the characteristic under measurement (in this case, output current of the DAC inverter 140). The data in this graph shows the value of the characteristic as it gets closer to the anomalous event. As one moves from right to left on the x-axis, the data begins to fluctuate and deviate from its regular pattern.

[0045] The neural network 200 is trained by feeding it data from signals similar to that shown in FIG. 3. The brackets 300 represent one exemplary data segment in the time series data of FIG. 3. Before being input to the neural network 200, the time series data is segmented into a plurality of data segments. For historical data used in training the neural network 200, the data segments are each assigned a time-to-event parameter representing the amount of time between the collection of the data in that segment and a known anomalous event that occurred after that data was collected. Each of the plurality of data segments, along with their assigned time-to-event parameters are input to the neural network 200 to train the network regarding the relationship(s) between the data and the time-to-event parameters.

[0046] After training, live (or recently collected) time series data can be segmented into similar data segments and input to the neural network 200. The trained neural network will then output a predicted time-to-event parameter for each inputted data segment. In this way, future anomalous events, as well as the amount of time until those events occur, can be predicted from the live data.

[0047] While certain illustrative embodiments have been described in detail in the figures and the foregoing description, such an illustration and description is to be considered as exemplary and not restrictive in character, it being understood that only illustrative embodiments have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected. There exist a plurality of advantages of the present disclosure arising from the various features of the apparatus, systems, and methods described herein. It will be noted that alternative embodiments of the apparatus, systems, and methods of the present disclosure may not include all of the features described, yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may readily devise their own implementations of the apparatus, systems, and methods that incorporate one or more of the features of the present disclosure.

WHAT IS CLAIMED IS:

1. A method comprising:

segmenting first time series data representing one or more characteristics of an electrical system into a first plurality of data segments;

assigning a time-to-event parameter to each of the first plurality of data segments, each time-to-event parameter representing an amount of time between the data in the corresponding data segment and an anomalous event associated with the electrical system; and

training a neural network using the first plurality of data segments together with the assigned time-to-event parameters.

2. The method of claim 1, wherein the first time series data are generated by one or more sensors measuring the one or more characteristics of the electrical system.

3. The method of claim 2, wherein the first time series data are collected from at least one of a solar panel array and a direct current to alternating current inverter.

4. The method of any preceding claim, further comprising:

segmenting second time series data representing the one or more characteristics of the electrical system into a second plurality of data segments; and

inputting one or more of the second plurality of data segments to the trained neural network to output a predicted time-to-event parameter for each inputted data segment, the predicted time-to-event parameter representing a predicted amount of time between the data in the inputted data segment and a predicted anomalous event associated with the electrical system.

5. The method of claim 4, wherein the second time series data represents the one or more characteristics of the electrical system during a later time period than the first time series data.

6. The method of claim 5, wherein each of the second plurality of data segments is input to the trained neural network in real time as the second time series data is collected and segmented.

7. The method of any one of claims 4-6, wherein the first time series data and the second time series data are each collected from at least one of a solar panel array and a direct current to alternating current inverter.

8. The method of any preceding claim, wherein the electrical system is a solar power plant or a subsystem thereof.

9. The method of claim 8, wherein the anomalous event corresponds with overheating of the electrical system.

10. The method of claim 8, wherein the anomalous event corresponds with a decrease in available sunlight.

11. The method of any one of claims 8-10, wherein the anomalous event corresponds to a reduction in power generation by the solar power plant.

12. The method of any preceding claim, wherein the anomalous event corresponds to a disruption in service of the electrical system.

13. The method of any preceding claim, wherein the electrical system consists of a single electrical device.

14. The method of any one of claims 1-12, wherein the electrical system comprises a collection of multiple electrical devices.

15. A method comprising:

segmenting live time series data representing one or more characteristics of an electrical system into a plurality of live data segments; and

inputting one or more of the plurality of live data segments to a trained neural network to output a predicted time-to-event parameter for each inputted data segment, the predicted time-to-event parameter representing a predicted amount of time between the data in the inputted data segment and a predicted anomalous event associated with the electrical system;

wherein the trained neural network was previously trained using a plurality of historical data segments each having an assigned time-to-event parameter, the plurality of historical data segments being generated from historical time series data representing the one or more characteristics of the electrical system, each assigned time-to-event parameter representing an amount of time between the data in the corresponding data segment and a historical anomalous event associated with the electrical system.

16. The method of claim 15, wherein the time series data are generated by one or more sensors measuring the one or more characteristics of the electrical system.

17. The method of claim 16, wherein first time series data are collected from at least one of a solar panel array and a direct current to alternating current inverter.

18. The method of any one of claims 15-17, wherein the electrical system is a solar power plant or a subsystem thereof.

19. The method of claim 18, wherein the anomalous event corresponds with overheating of the electrical system.

20. The method of claim 18, wherein the anomalous event corresponds with a decrease in available sunlight.

21. The method of any one of claims 18-20, wherein the anomalous event corresponds to a reduction in power generation by the solar power plant.

22. The method of any one of claims 15-21, wherein the anomalous event corresponds to a disruption in service of the electrical system.

23. The method of any one of claims 15-22, wherein the electrical system consists of a single electrical device.

24. The method of any one of claims 15-22, wherein the electrical system comprises a collection of multiple electrical devices.

25. One or more computer-readable media storing a plurality of instructions that, when executed by a power controller operatively connected to (i) at least one solar panel array and (ii) an inverter electrically coupled to the at least one solar panel array, cause the power controller to perform the method of any one of the preceding claims.

26. A power controller to be operatively connected to (i) at least one solar panel array and (ii) an inverter electrically coupled to the at least one solar panel array, the power controller being configured to perform the method of any one of claims 1-24.

27. A power plant comprising:

at least one solar panel array;

an inverter electrically coupled to the at least one solar panel array; and

a power controller operatively connected to the at least one solar panel array and to the inverter, the power controller being configured to perform the method of any one of claims 1-24.

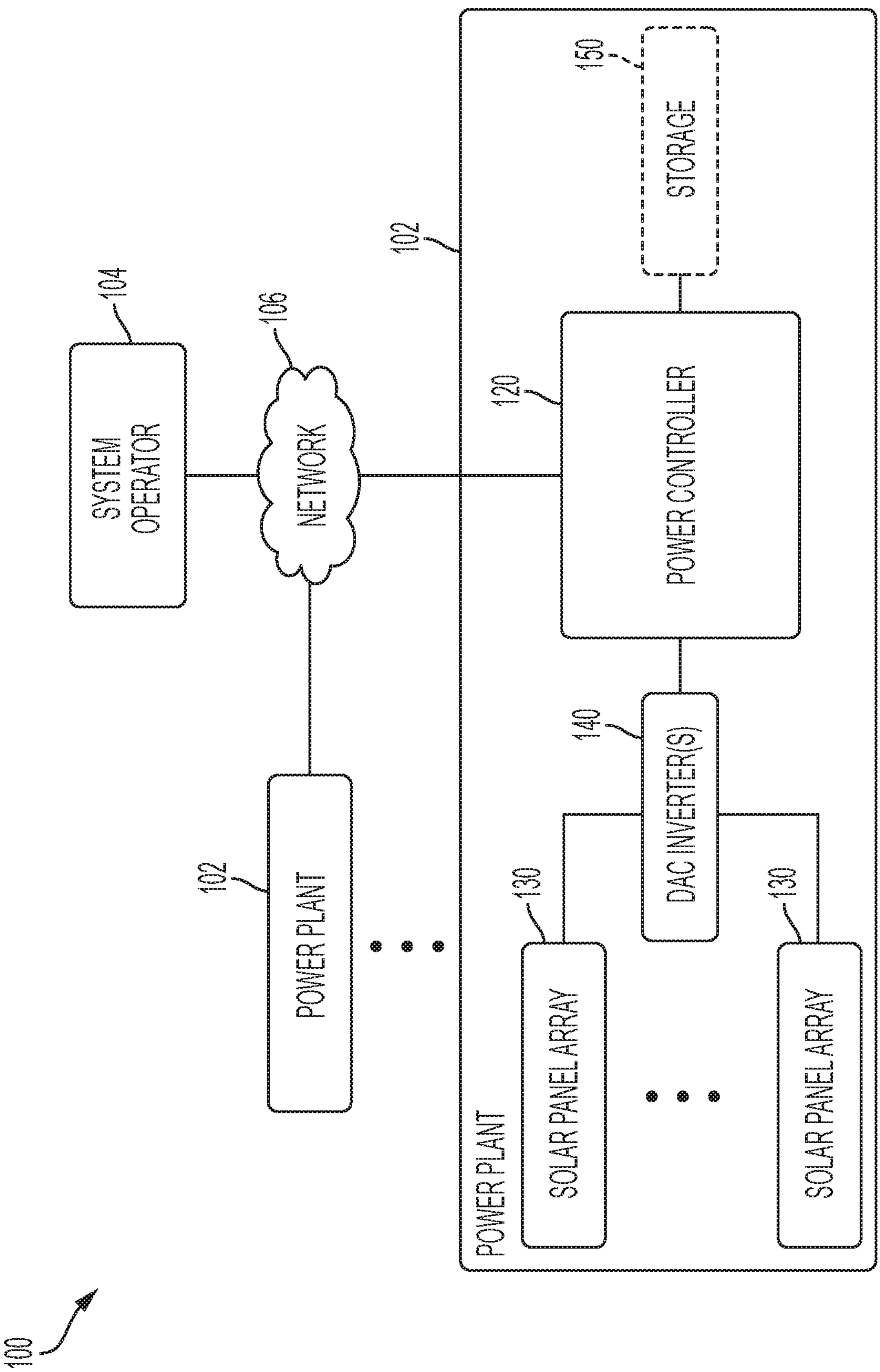
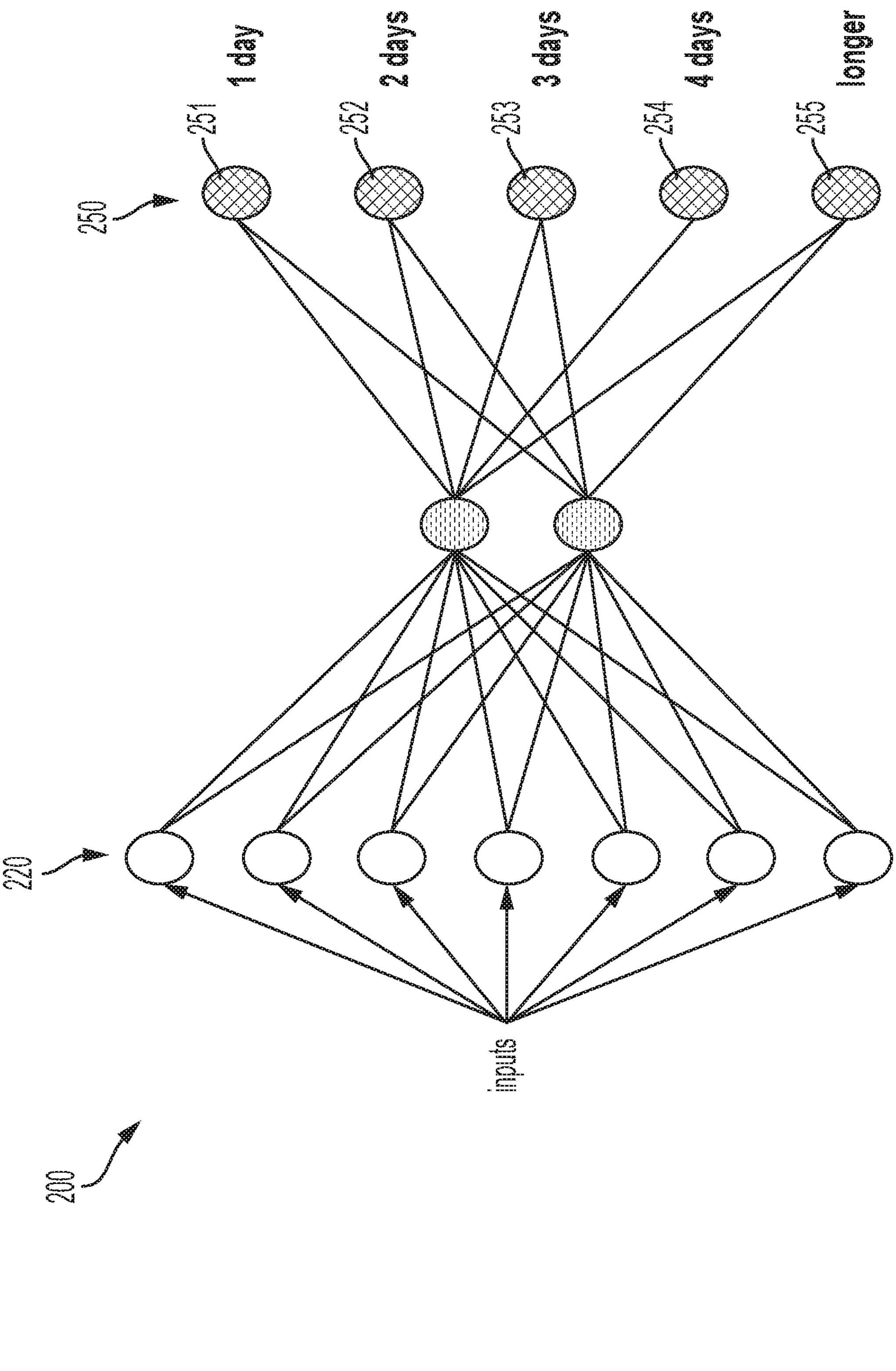

SYSTEM OPERATOR
104
NETWORK
106
POWER PLANT
102
102
POWER PLANT
POWER CONTROLLER
120
STORAGE
150
DAC INVERTER(S)
140
SOLAR PANEL ARRAY
130
SOLAR PANEL ARRAY
130
100

FIG. 1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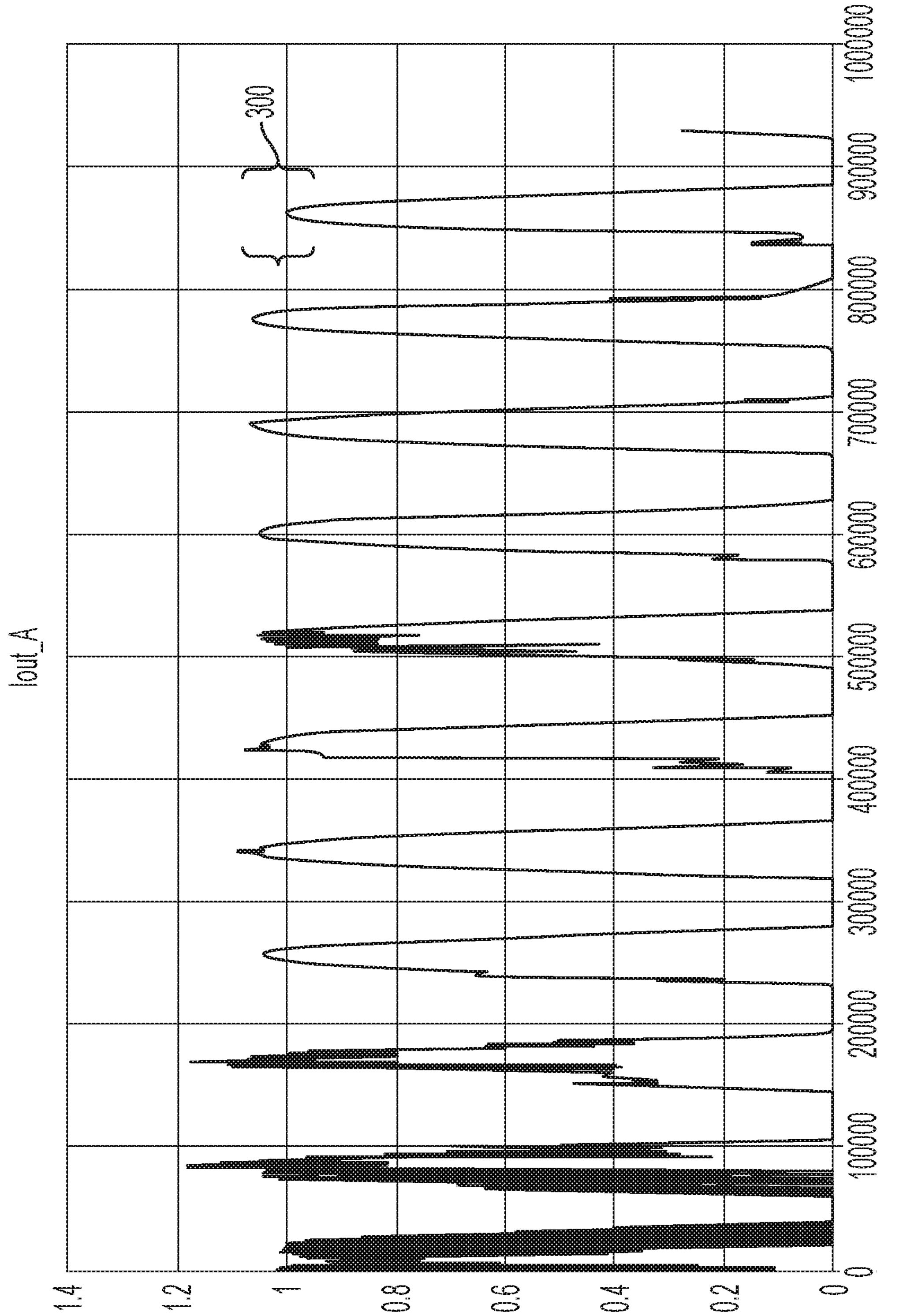
220
250
251
252
253
254
255
1 day
2 days
3 days
4 days
longer

FIG. 2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1.4
1.2
1
0.8
0.6
0.4
0.2
0
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300000
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500000
600000
700000
800000
900000
1000000

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/040664

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G05B 13/04; H02S 20/32; H04Q 9/00 (2019.01)

CPC - G05B 13/048; H02S 20/32; F24S 50/00; G01R 19/00; H02J 3/383; H02S 50/00; H04Q 9/00 (2019.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 307/80; 307/151; 702/3 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	GREEN et al. "Improving Efficiency of PV Systems Using Statistical Performance Monitoring," IEA PVPS Task 13, Subtask 2, Report IEA-PVPS T13-07:2017 June 2017 ISBN 978-3-906042-48-0 [retrieved on 2019-09-07]. Retrieved from the Internet: <URL: http://iea-pvps.org/fileadmin/dam/public/report/technical/Report_IEA-PVPS_T13-07_2017_Improving_Efficiency_of_PV_Systems_Using_Statistical__Performance_Monitoring.pdf> pp 1-55	1-6, 15-18, 20 --- 19
Y	US 2010/0201374 A1 (VASILYEV et al) 12 August 2010 (12.08.2010) entire document	19
A	WO 2010/042533 A2 (ATONOMETRICS, INC.) 15 April 2010 (15.04.2010) entire document	1-6, 15-20
A	US 2012/0166085 A1 (GEVORKIAN) 28 June 2012 (28.06.2012) entire document	1-6, 15-20
A	US 2018/0046924 A1 (GUANGZHOU INSTITUTE OF ENERGY CONVERSION, CHINESE ACADEMY OF SCIENCES) 15 February 2018 (15.02.2018) entire document	1-6, 15-20
A	US 2016/0190981 A1 (INDUSTRY-ACADEMIC COOPERATION FOUNDATION, YONSEI UNIVERSITY) 30 June 2016 (30.06.2016) entire document	1-6, 15-20
A	WO 2016/069810 A1 (SINEWATTS, INC. et al) 06 May 2016 (06.05.2016) entire document	1-6, 15-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 September 2019	30 SEP 2019

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/040664

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 7-14, 21-27
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.