SOLAR-ENERGY HARVESTING APPARATUSES, SOLAR-PANEL SYSTEMS, AND METHODS FOR INSTALLATION AND USING OF SAME

FIELD OF THE DISCLOSURE

The present disclosure relates generally to solar-energy harvesting apparatuses, solar-panel systems, and methods for installing and using the solar-energy harvesting apparatuses and solar-panel systems, and in particular to integrated hybrid solar-energy harvesting/storage apparatuses, systems, and methods for installation and using of same.

BACKGROUND

Solar energy has emerged as a vital renewable energy source, offering a sustainable and clean alternative to the conventional power generation. Photovoltaic (PV) panels (also called "solar panels") generally comprise interconnected photovoltaic cells for converting solar energy into usable electricity. The quest for efficient and aesthetically pleasing solar-panel solutions has driven advancements in the field of renewable energy. However, current solar panel designs face several limitations with respect to the mechanical structures holding the panels. One of the key limitations lies in the complexity and time-consuming nature of solar-panel installations. Traditional designs require the attachment of external components such as junction boxes, wiring, microinverter, optimizers, and support structures after panel installation. This fragmented approach not only increases the labor and material costs but also introduces potential points of failure such as loose connections and susceptibility to environmental damage. Additionally, the visual impact of solar panels on building aesthetics has been a concern for homeowners. The disjointed appearance resulting from external wiring and attachments compromises the overall aesthetic appeal of solar-panel installations, limiting their integration into residential, commercial, and urban environments.

Thus, the requirement of separate installations of various components in traditional solar panel designs often results in increased complexity, installation time, and maintenance efforts. Innovative solar panels, systems, and installation and use methods are desired for solve such issues.

SUMMARY

In view of above-described disadvantages, embodiments disclosed herein relate to novel solar-energy harvesting apparatuses, systems, and installation methods.

According to one aspect of this disclosure, there is provided an integrated solar-panel configuration with all electronics and energy-storage modules incorporated therewithin for providing an all-in-one hybrid energy harvesting/storage solution. The solar-energy harvesting

apparatuses and systems disclosed herein provide improved performance, ease of installation and maintenance, a visually appeasing presentation, and elimination of the need for massive external installation and wiring otherwise needed for systems using separate microinverters, optimizers, storage systems, and/or other external components.

According to one aspect of this disclosure, there is provided a solar-energy harvesting apparatus comprising: a base structure; a photovoltaic (PV) module coupled to a first side of the base structure; and one or more electronic modules and/or one or more energy-storage modules coupled to an opposite, second side of the base structure; the base structure comprises: a first coupling tab and a second on two lateral sides of the base structure positioned at a front side thereof, and at least one hinge at a rear side of the base structure, the at least one hinge comprising a third coupling tab.

According to one aspect of this disclosure, there is provided a solar-energy harvesting apparatus comprising: a base structure; a PV module demountably coupled to a first side of the base structure; and one or more electronic modules and/or one or more energy-storage modules demountably coupled to a second side of the base structure.

In some embodiments, the first side is a top side, and the second side is a bottom side.

In some embodiments, the base structure is made of injection moldable NORYL GFN1 resin with 10% glass reinforced blend of polyphenylene ether and polystyrene.

In some embodiments, the base structure comprises a sealing groove on the first side thereof for receiving a sealing component therein for sealably engaging the PV module and preventing water leaking to the one or more electronic modules and/or one or more energy-storage modules.

In some embodiments, the base structure comprises a first coupling structure and a second coupling structure on two laterally opposite sides of the base structure positioned at or in proximity with a rear side thereof; and the first and second coupling structures are positioned such that, when two solar-energy harvesting apparatuses are arranged laterally side-by-side, the first coupling structure of a first one of the two solar-energy harvesting apparatuses overlaps with or side-by-side with the second coupling structure of a second one of the two solar-energy harvesting apparatuses.

In some embodiments, when the two solar-energy harvesting apparatuses are arranged laterally side-by-side, the first and second coupling structures are securable by a securing apparatus; the securing apparatus comprises two hollow legs for extending through holes on the overlapped or side-by-side coupling structures of the two solar-energy harvesting apparatuses; and each hollow leg of the securing apparatus comprises a bore for receiving a nut extending therethrough for securing the two solar-energy harvesting apparatuses on a securing base.

In some embodiments, when the securing apparatus comprises a hollow body having an open top, a bottom wall, and two holes on the bottom wall thereof; and each hollow leg is extended outwardly from the bottom wall of the hollow body with the bore of the hollow leg connected to a respective one of the two holes on the bottom wall of the hollow body.

In some embodiments, when the securing apparatus comprises a cover engageable to the open top of the hollow body.

In some embodiments, the securing base is a rail; and the rail comprises a first elongated slot having two shoulders on opposite sides thereof for sliding in and engaging therewith a head of the nut for securing the two solar-energy harvesting apparatuses on a securing base.

In some embodiments, the base structure comprises a pair of downwardly extending and laterally outwardly facing steps on or in proximity with the laterally opposite sides of the base structure, such that, when the two solar-energy harvesting apparatuses are arranged side-by-side and positioned onto the rail, the adjacent steps of the two solar-energy harvesting apparatuses form a delimiting structure for delimiting the rail therebetween.

In some embodiments, the rail comprises a second elongated slot on a sidewall thereof, the second elongated slot comprising two shoulders on opposite sides thereof for sliding in and engaging therewith a head of a nut for securing the rail to a leg.

In some embodiments, the base structure comprises a third coupling structure and a fourth coupling structure on the two laterally opposite sides of the base structure positioned at or in proximity with a front side thereof; and the third and fourth coupling structures are positioned such that, when the two solar-energy harvesting apparatuses are arranged laterally side-by-side, the third coupling structure of the first one of the two solar-energy harvesting apparatuses overlaps with or side-by-side with the fourth coupling structure of the second one of the two solar-energy harvesting apparatuses.

In some embodiments, each of the first and second coupling structures is coupled to the base structure via a hinge such that the solar-energy harvesting apparatus is pivotable around the hinge with respect to the first and second coupling structures.

In some embodiments, the first coupling structure is on an arm, and the arm is coupled to the base structure via the hinge; and the arm is receivable in an elongated recess of the base structure.

In some embodiments, the elongated recess of the base structure receives therein a stand; and the stand is rotatable out of the elongated recess of the base structure for supporting the solar-energy harvesting apparatus.

In some embodiments, the arm comprises a notch; and the stand comprises a tip engageable with the notch when the stand and the arm are rotated out of the elongated recess of the

base structure.

In some embodiments, the base structure comprises a plurality of air vents on one or more sidewalls thereof, and a plurality of tabs each positioned beside one of the plurality of air vents for guiding the airflow.

In some embodiments, each of the one or more electronic modules and the one or more energy-storage modules comprises: an enclosure having a plurality of heat-conductive fins on the second side thereof for heat dissipation; a cover coupled to the first side of the enclosure for closing the enclosure; an electromagnetic shield layer 126 attached to an interior side of the cover for shielding electromagnetic interferences; and a heat deflector coupled to an exterior side of the cover.

In some embodiments, the cover comprises a plurality of spacers on the exterior side thereof for supporting the heat deflector and maintaining a gap between the heat deflector and the cover.

In some embodiments, the cover is a thermal-resistive cover.

In some embodiments, the one or more electronic modules comprise one or more control circuits for managing energy flow between the PV module, the one or more energy-storage modules, and output of the solar-energy harvesting apparatus using an artificial intelligence (AI) engine to optimize electricity consumption cost for an electricity user of the solar-energy harvesting apparatus.

In some embodiments, the AI engine comprises a machine learning (ML) engine with a cost function:

$$CostFunc(d,m) = \sum_{h=1}^{24} A(h,d,m) \times B(h,d,m)$$

where A is a function of the electricity-consumption cost per watt-hour (Wh) at a time of hour h of day d and month m, and function B is a function of the Wh energy usage and

$$B(h, d, m) = Load(h,d,m) + Storage(h,d,m) - PV(h, d, m)$$

where $Load(h, d, m)$ is electricity consumption of the one or more electricity-consuming devices at the time, $Storage(h, d, m)$ is an amount of stored energy of the one or more energy-storage modules, and $PV(h, d, m)$ is an amount of solar energy harvested by the one or more PV modules.

In some embodiments, the ML engine is configured for predicting the energy consumption by the electricity user and the amount of solar energy harvesting for adjust times of charging and discharging the one or more energy-storage modules to minimize the cost function.

According to one aspect of this disclosure, there is provided a computerized method comprising: minimizing electricity-consumption cost of a system using an artificial intelligence method.

In some embodiments, the system comprises: one or more PV modules, one or more energy-storage modules, and one or more electricity-consuming devices; and said minimizing electricity-consumption cost using the artificial intelligence method comprises: minimizing the electricity-consumption cost using a machine learning method with a cost function:

$$CostFunc(d,m) = \sum_{h=1}^{24} A(h,d,m) \times B(h,d,m)$$

where A is a function of the electricity-consumption cost per watt-hour (Wh) at a time of hour h of day d and month m, and function B is a function of the Wh energy usage and

$$B(h, d, m) = Load(h,d,m) + Storage(h,d,m) - PV(h, d, m)$$

where $Load(h, d, m)$ is electricity consumption of the one or more electricity-consuming devices at the time, $Storage(h, d, m)$ is an amount of stored energy of the one or more energy-storage modules, and $PV(h, d, m)$ is an amount of solar energy harvested by the one or more PV modules.

In some embodiments, the computerized method further comprises: controlling time of charging and discharging the one or more energy-storage modules based on said minimization.

In some embodiments, said optimizing electricity-consumption cost using the artificial intelligence method comprises: predicting $Load(h, d, m)$ based on historical data of electricity usage;

In some embodiments, said optimizing electricity-consumption cost using the artificial intelligence method comprises: predicting $PV(h, d, m)$ based on: a weather pattern and a solar radiation pattern, historical data of harvested solar energy, or a combination thereof.

In some embodiments, said optimizing electricity-consumption cost using the artificial intelligence method comprises: predicting $PV(h, d, m)$ based on a weather pattern and a solar radiation pattern.

According to one aspect of this disclosure, there is provided one or more processors functionally connected to one or more computer-readable storage media for performing the above-described method.

In some embodiments, the instructions, when executed, cause one or more circuits to perform the above-described method.

According to one aspect of this disclosure, there is provided a system comprising: a plurality of units comprising a master unit, one or more intermediate units $U_1, \ldots, U_n$, and an end unit connected in series beginning from the master unit and ending by the end unit, where $n \geq 1$ is an integer; the i-th intermediate unit ($i = 1, 2, \ldots, n$) is configured for: receiving a triggering signal from an immediately previous one of the plurality of units, the immediately previous one of the plurality of units being the master unit if $i = 1$, or being the (i-1)-th unit if $i > 1$, communicating

with the master unit via a communication channel regarding a unique identifier of the i-th intermediate unit, and sending the triggering signal to an immediately next one of the plurality of units, the immediately next one of the plurality of units being the end unit if i = n, or being the (i+1)-th unit if i < n.

In some embodiments, said communicating with the master unit regarding the unique identifier of the i-th intermediate unit comprises: sending a request to the master unit, receiving the unique identifier from the master unit; or said communicating with the master unit regarding the ID of the i-th intermediate unit comprises: reporting the unique identifier to the master unit.

In some embodiments, the i-th intermediate unit is further configured for: sending an acknowledgement to the master unit via the communication channel after receiving the unique identifier from the master unit.

In some embodiments, the end unit is configured for: receiving the trigger signal; and sending a feedback signal via the feedback channel.

In some embodiments, each of the plurality of units comprises: a feedback port connecting to a feedback channel, and a communication port connecting to the communication channel; the master unit further comprises a next port for sending the triggering signal; the end unit further comprise a previous port for receiving the triggering signal; each of the one or more intermediate units further comprises: a previous port for receiving the triggering signal, and a next port for sending the triggering signal; and the previous port of the i-th intermediate unit is connected to the next port of the immediately previous one of the plurality of units, and the next port of the i-th intermediate unit is connected to the previous port of the immediately next one of the plurality of units.

In some embodiments, the communication channel comprises a first communication line and a second communication line; and the communication port of each of the plurality of units comprises a first communication terminal connecting to the first communication line, and a second communication terminal connecting to the second communication line.

In some embodiments, the feedback channel comprises a feedback line; and the feedback port of each of the plurality of units is connected to the feedback line.

In some embodiments, said sending the trigger signal performed by the i-th intermediate unit comprises: changing the next port from a first state to a second state; said receiving the trigger signal performed by the i-th intermediate unit or by the end unit comprises: detecting that the previous port is changed from the first state to the second state; and said sending the feedback signal performed by the end unit comprises: changing the feedback port from a third state to a fourth state.

In some embodiments, the first state is a LOW state, the second state is a HIGH state, the

third state is the LOW state, and the fourth state is the HIGH state.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the disclosure, reference is made to the following description and accompanying drawings, in which:

FIG. 1A is a perspective view of a solar-energy harvesting apparatus, according to some embodiments of this disclosure;

FIG. 1B is an exploded perspective view of the solar-energy harvesting apparatus shown in FIG. 1A;

FIG. 2 is an exploded perspective view of the energy-storage module of the solar-energy harvesting apparatus shown in FIG. 1A, according to some embodiments of this disclosure;

FIG. 3 is an exploded perspective view of an electronic module of the solar-energy harvesting apparatus shown in FIG. 1A, according to some embodiments of this disclosure;

FIGs. 4A and 4B are perspective views of the solar-energy harvesting apparatus shown in FIG. 1A, according to some embodiments of this disclosure, the solar-energy harvesting apparatus comprising one electronic module and three energy-storage modules, wherein

FIG. 4A is a perspective view of the solar-energy harvesting apparatus viewed from the top side thereof, and

FIG. 4B is a perspective view of the solar-energy harvesting apparatus viewed from the bottom side thereof;

FIGs. 5A and 5B are perspective views of a frame of the energy-storage module of the solar-energy harvesting apparatus shown in FIG. 1A viewed from different angles of the top side thereof, according to some embodiments of this disclosure;

FIGs. 6A and 6B are perspective views of the frame shown in FIG. 5A viewed from different angles of the bottom side thereof;

FIGs. 7 to 12 are the plan view, bottom view, front view, rear view, left side view, and right side view of the frame shown in FIG. 5A, respectively;

FIG. 13 is a perspective view of a first hinge of the frame shown in FIG. 5A, according to some embodiments of this disclosure;

FIGs. 14A and 14B are perspective views of a second hinge of the frame shown in FIG. 5A, viewed from different angles of the top side thereof, according to some embodiments of this disclosure;

FIG. 15 is a perspective view of a stand of the frame shown in FIG. 5A, according to some embodiments of this disclosure;

FIG. 16 is a perspective view of a rail for mounting the solar-energy harvesting apparatus

shown in FIG. 1A to a surface, according to some embodiments of this disclosure;

FIG. 17 is a cross-sectional view of the rail shown in FIG. 16 along the cross-section line A-A;

FIG. 18 is a perspective view of a roof with a plurality of rails shown in FIG. 16 mounted thereon, according to some embodiments of this disclosure;

FIG. 19A is a plan view of two solar-energy harvesting apparatuses shown in FIG. 1A arranged side-by-side for installation to the rail shown in FIG. 16;

FIG. 19B is an enlarged plan view of the portion B of the two solar-energy harvesting apparatuses shown in FIG. 19A;

FIGs. 20A to 20D are the perspective view, plan view, front view, and side view of a coupling tool for coupling the two solar-energy harvesting apparatuses shown in FIG. 19A to a rail shown in FIG. 16, according to some embodiments of this disclosure;

FIG. 21 is a perspective view showing a portion of the two solar-energy harvesting apparatuses shown in FIG. 19A engaged by the coupling tool shown in FIG. 20A for coupling to a rail shown in FIG. 16;

FIG. 22A is a cross-sectional view showing the portion of the two solar-energy harvesting apparatuses shown in FIG. 21 coupled to a rail shown in FIG. 16 using the coupling tool shown in FIG. 20A;

FIG. 22B is a perspective view of the portion of the two solar-energy harvesting apparatuses shown in FIG. 21 coupled to the rail shown in FIG. 16 using the coupling tool shown in FIG. 20A;

FIG. 23 is a perspective view of the two solar-energy harvesting apparatuses shown in FIG. 21 coupled to the rail shown in FIG. 16 using the coupling tool shown in FIG. 20A;

FIGs. 24A and 24B are a side view and a perspective view of a solar-energy harvesting apparatus shown in FIG. 23 in the lifted status;

FIG. 24C is a perspective view of a plurality of solar-energy harvesting apparatuses in the lifted status;

FIG. 25 is a perspective view of a rail for mounting the solar-energy harvesting apparatus shown in FIG. 1A to a surface, according to some embodiments of this disclosure;

FIG. 26 is a perspective view of a based on the rail shown in FIG. 25;

FIG. 27 is a perspective view of a solar-energy harvesting apparatus used in a thermal simulation;

FIG. 28 shows the thermal simulation results;

FIGs. 29A to 29E show an example of the electricity costs for a single day using various systems, wherein:

FIGs. 29A and 29B shows the electricity rates offered by a utility company, showing the off-peak, mid-peak, and on peak time ranges for weekdays (FIG. 29A) and weekends (FIG. 29B),

FIG. 29C illustrates a typical load entirely supplied by the power grid in absence of any solar system,

FIG. 29D illustrates a typical load supplied by solar panels without any energy storage system, and

FIG. 29E illustrates a typical load supplied by solar panels and energy storage;

FIG. 30 is a schematic diagram showing a power system deployed in a site and using an auto-identification method for device recognition and configuration, according to some embodiments of this disclosure;

FIG. 31 is a schematic diagram showing a master unit, one or more intermediate units such as solar panels, and an end unit of the power system, and the connection thereof, according to some embodiments of this disclosure;

FIG. 32 is a schematic diagram showing the detail of an intermediate unit, according to some embodiments of this disclosure;

FIG. 33 is a schematic diagram showing the detail of the connection of the master unit, the one or more intermediate units, and the end unit, according to some embodiments of this disclosure; and

FIG. 34A is a perspective view of a rail, according to some embodiments of this disclosure; and

FIG. 34B is a cross-sectional view of two solar-energy harvesting apparatuses mounted under the rail shown in FIG. 34A, according to some embodiments of this disclosure.

DETAILED DESCRIPTION

A. SOLAR-ENERGY HARVESTING APPARATUS

Turning now to FIGs. 1A and 1B, a solar-energy harvesting apparatus (also called a "solar panel") according to some embodiments of this disclosure is shown and is generally identified using reference numeral 100. FIGs. 1A and 1B also show a coordinate system defining a longitudinal direction, a lateral direction, and a vertical direction, and also defining a top side and a bottom side along the vertical direction, a front side and a rear side along the longitudinal direction, and a left side and a right side along the lateral direction. Such a coordinate system and the directions defined therewith are only used for ease of illustration and description, and do not necessarily correspond to the real-world coordinate system and directions.

As shown in FIGs. 1A and 1B, the solar-energy harvesting apparatus 100 comprises a

photovoltaic (PV) module 102, a base structure 104 in the form of a frame, one or more energy-storage modules 106, and one or more electronic modules 108.

The PV module 102 may be any suitable PV panels such as an "off-the-shelf" or custom-made PV panel, and comprises an enclosure receiving therein one or more PV cells and necessary circuits. As shown in FIGs. 1A and 1B, the PV module 102 is secured to the top side of the frame 104 using suitable fastening methods such as gluing, screwing, nailing, and/or the like.

The one or more energy-storage modules 106 and the one or more electronic modules 108 are coupled to the bottom side of the frame 104 using suitable fastening methods such as gluing, screwing, nailing, and/or the like.

Each energy-storage module 106 comprises an enclosure receiving therein one or more suitable energy-storage components (for example, one or more batteries and/or one or more supercapacitor cells) and necessary circuits. Each electronic module 108 comprises an enclosure receiving therein one or more control circuits received therein. The control circuits of the one or more electronic modules 108 may be interconnected and/or connected to the circuits of the PV module 102 and the one or more energy-storage modules 106, for controlling the operation of the PV module 102 and the one or more energy-storage modules 106, and for other purposes as needed.

FIG. 2 is an exploded perspective view of the energy-storage module 106. As shown, the energy-storage module 106 comprises an enclosure 122 having a plurality of heat-conductive fins 132 on the bottom side thereof for heat dissipation, and one or more suitable energy-storage components 124 (for example, one or more batteries and/or one or more supercapacitor cells) and necessary circuits (not shown) received in the enclosure 122. The size of the energy-storage module 106 depends largely on the size and the number of the energy-storage components 124.

A cover 128 is coupled to the top side of the enclosure 122 for closing the enclosure 122 and securing the energy-storage components 124 and circuits therein. In these embodiments, the energy-storage module 106 also comprises an electromagnetic shield layer 126 (such as a layer of tin) attached to the interior side of the cover 128 for protecting the energy-storage components 124 and circuits from external electromagnetic interferences (EMIs), and a radiation or heat deflector 130 coupled to the exterior side of the cover 128. As shown in FIG. 2, the cover 128 may optionally comprise a plurality of spacers 134A and 134B on the exterior side thereof for supporting the radiation deflector 130 and maintaining a gap between the radiation deflector 130 and the cover 128 for preventing oil canning of the metal radiation deflector 130. As those skilled in the art understand, oil canning is a distortion in the flat areas of metal panels.

In these embodiments, each spacer 134A may comprise a hole for extending a screw therethrough for fastening the cover 128 to the enclosure 122, and/or for fastening the energy-storage module 106 to the frame 104.

The energy-storage module 106 reconciles the time mismatch between solar-energy harvesting by the PV module and energy consumption by the devices (not shown) connected to the output of the solar-energy harvesting apparatus 100. The energy-storage module 106 provides a reliable source of energy for locations with unstable or without grid connections. In addition, the energy-storage module 106 may be used to economize electricity consumptions in areas with tiered-pricing utilities where electricity consumption cost and the price of energy injection to the power grid are not at fixed rates and time-dependent.

FIG. 3 is an exploded perspective view of the electronic module 108. As shown, the electronic module 108 in these embodiments has a similar structure as that of the energy-storage module 106. More specifically, the electronic module 108 comprises an enclosure 142 having a plurality of heat-conductive fins 152 on the bottom side thereof for heat dissipation, and one or more control circuits 144 (such as in the form of one or more printed circuit boards (PCBs)) received in the enclosure 122.

A cover 148 is coupled to the top side of the enclosure 142 for closing the enclosure 142 and securing the circuits 144 therein. In these embodiments, the electronic module 108 also comprises an electromagnetic shield layer 146 attached to the interior side of the cover 148 for protecting the circuits 144 from external electromagnetic interferences, and a radiation or heat deflector 150 coupled to the exterior side of the cover 148. As shown in FIG. 3, the cover 148 may optionally comprise a plurality of spacers 154A and 154B on the exterior side thereof for supporting the radiation deflector 150 and maintaining a gap between the radiation deflector 150 and the cover 148 for preventing oil canning of the radiation deflector 150. In these embodiments, each spacer 154A may comprise a hole for extending a screw therethrough for fastening the cover 148 to the enclosure 142, and/or for fastening the electronic module 108 to the frame 104.

The one or more control circuits 144 of the electronic module 108 manage the energy flow direction between the PV cells, energy-storage components 124, and the output of the solar-energy harvesting apparatus 100 (which may be connected to the power grid and/or energy-consumption devices or loads).

The integration of energy-storage module 106 (and more specifically the energy-storage components 124) and the electronic module 108 within the solar-energy harvesting apparatus 100 eliminates the necessity of excess circuitry and associated loss for direct current (DC) to alternate current (AC) conversion otherwise required in the central energy-storage solutions. Also, in some embodiments, the distributed configuration of energy-storage components 124 in a plurality of energy-storage modules 106 of one or more solar-energy harvesting apparatuses 100 eases thermal management of the energy-storage components 124 and allows full control on the individual energy-storage components 124, which is a feature unavailable to centralized storage solutions.

As those skilled in the art will appreciate, the number of the energy-storage modules 106 and/or the number of the electronic modules 108 may vary and may be easily customized to adapt to the practical needs, thereby providing a modular and distributed solution. For example, FIG. 1A shows a solar-energy harvesting apparatus 100 comprising one electronic module 108 and one energy-storage module 106, while FIGs. 4A and 4B show a solar-energy harvesting apparatus 100 comprising one electronic module 108 and three energy-storage modules 106.

Such a modular and distributed solution provides many advantages. For example, the modular and distributed configuration of energy-storage modules 106 provides the ease of the design and/or customization of a solar-storage system to provide virtually exactly the capacity required in a specific application. This is in contrast to the conventional centralized energy-storage solutions where an increase in capacity usually requires the addition of another fully centralized storage system often with significantly more than the actual capacity needed.

FIGs. 5A to 12 show the frame 104 in various views, according to some embodiments of this disclosure. In these embodiments, the frame 104 has a rectangular shape and is made of injection moldable NORYL GFN1 resin with 10% glass reinforced blend of polyphenylene ether and high impact polystyrene. This material provides a number of advantages such as very low moisture absorption, high strength, high hydraulic stability, low warpage, low specific gravity, high thermal conductivity, high dimensional stability, and the like, thereby rendering it as a good material for outdoor applications. Of course, those skilled in the art will appreciate that, in other embodiments, the frame 104 may be made of any other suitable materials such as plastic, metal, and/or the like.

As shown in FIGs. 5A to 12, the frame 104 comprises a top interface 202 for demountably coupling to the PV module 102, and a bottom interface 212 for coupling to the one or more energy-storage modules 106 and the one or more electronic modules 108. The top interface 202 comprises a groove 204 along the edge thereof for receiving a sealing component to provide a sealed coupling between the PV module 102 and the frame 104.

The frame 104 also comprises a plurality of air vents or openings 206 on one or more sidewalls thereof. For example, FIGs. 5A to 12 show the frame 104 having a plurality of air vents or openings 206 on two laterally opposite sidewalls 208A and 208B thereof. The plurality of air vents or openings 206 facilitate airflow, allowing efficient convection heat transfer and providing efficient cooling. In these embodiments, the frame 104 also comprises a plurality of tabs 216 each positioned beside a vent 206 for guiding the airflow to further improve the convection heat transfer.

Each of the lateral sidewalls 208A and 208B comprises a coupling structure 222 such as a coupling tab extending laterally outwardly from a position at or near the front end thereof. The coupling tab 222 comprises one or more holes 224 (such as a single hole 224) for extending a

fastening screw therethrough. The positions of the coupling tabs 222 may be longitudinally arranged at any suitable positions for east of fastening. For example, in these embodiments, when two solar-energy harvesting apparatuses 100 are arranged side-by-side, the neighboring coupling tabs 222 of the two solar-energy harvesting apparatuses 100 are longitudinally side-by-side and adjacent to each other (described in more detail later).

Each of the lateral sidewalls 208A and 208B also comprises a hinge 232 (also denoted 232A and 232B corresponding to sidewalls 208A and 208B, respectively) rotatably coupled to a pivot 234 (see FIG. 8) at a position at or near the rear end thereof. In these embodiments, each hinge 232 is in the form of a pivotable arm, and is rotatable about the pivot 236 between a first position parallel to the frame 104 (that is, at a zero-degree angle with respect to the frame 104) and a second position unparallel to the frame 104 (that is, at a non-zero-degree angle with respect to the frame 104).

As shown in FIG. 13, the hinge 232A comprises a coupling tab 236 near the pivot 234 thereof. The coupling tab 236 comprises a hole 238 (such as a slotted hole or any other suitable hole) for extending a fastening screw therethrough. The hinge 232A also comprises a stand-positioning structure 240 (such as a hole, a notch, or the like) at a position away from the pivot 234.

As shown in FIGs. 14A and 14B, the hinge 232B comprises two coupling tabs 246A and 246B near the pivot 234 thereof. Each of the coupling tabs 246A and 246B comprises a hole 238 for extending a fastening screw therethrough. In these embodiments, the coupling tabs 246A and 246B are arranged at suitable positions such that, when two solar-energy harvesting apparatuses 100 are side-by-side, the coupling tab 236 of one solar-energy harvesting apparatus 100 is side-by-side with the "higher" coupling tab 246A of the other solar-energy harvesting apparatus 100, and is on top of and longitudinally overlaps with the "lower" coupling tab 246A of the other solar-energy harvesting apparatus 100 such that the holes 238 of the two coupling tabs 236 and 246A are aligned.

Those skilled in the art will appreciate that the hinges 232 may be rotatably coupled to the lateral sidewalls 208A and 208B of the frame 104 in any suitable manner. For example, as shown in FIGs. 6A, 6B, and 8, the hinge 232A is rotatably coupled to the lateral sidewall 208A of the frame 104 in such a way that the hinge 232A is received in a longitudinally elongated recess 238 on the lateral sidewall 208A when the hinge 232A is rotated to the first position parallel to the frame 104. On the other hand, the lateral sidewall 208B of the frame 104 does not comprise a similar longitudinally elongated recess, and the hinge 232B is rotatably coupled to the lateral sidewall 208B of the frame 104 such that the hinge 232B is positioned beside the lateral sidewall 208B when the hinge 232B is rotated to the first position parallel to the frame 104.

As shown in FIGs. 6A, 6B, 8, and 11, the lateral sidewall 208A further comprises a

stand 252 coupled to a pivot 256 thereof, and is rotatable between a first position parallel to the frame 104 and received in the longitudinally elongated recess 238 on the lateral sidewall 208A, and a second position unparallel to the frame 104. As shown in FIG. 15, the stand is in the form of a stick (or in any other suitable form) having a tip 258 distal to the pivot 256.

Referring again to FIGs. 5A to 6B and 9 to 12, on each of the front and rear sides, the frame 104 comprises a pair of downwardly extending steps 262 each on a laterally inner side of a respective coupling tab 222, 236, or 246A. The use of the steps 262 will be described later.

One or more solar-harvesting apparatuses 100 may be installed on a surface such as a roof of a building. In some embodiments, one or more solar-harvesting apparatuses 100 may be installed on the surface via a plurality of rails.

As shown in FIGs. 16 and 17, the rail 300 comprises an elongated body 302 mountable to a surface 304, for example, via a plurality of legs 306. The body 302 comprises a top surface 312 with an elongated slot 314 thereon. The slot 314 has a narrowed top opening thereby forming a pair of elongated, downwardly facing shoulders 316 on the opposite sides of the slot 314.

In some embodiments, the body 302 of the rail 300 also comprises a pair of elongated slots 318 on opposite sidewalls of the rail 300. Each side slot 318 has a structure similar to that of the top slot 314. Each leg 306 comprises a vertically slotted hole 308. Thus, each leg 306 may be coupled to the body 302 by loosely extending a bolt (not shown) through the slotted hole 308, then sliding the head of the bolt into the side slot 318, and tightening a nut 310 onto the bolt to secure the leg 306 to the body 302. By positioning the bolt at various positions of the slotted hole 308, the height of the rail 300 may be adjusted.

The installation process of a plurality of solar-harvesting apparatuses 100 is now described using an example of two solar-harvesting apparatuses 100.

As shown in FIG. 18, a plurality of rails 300 are first mounted to a surface 304 in parallel with each other and with a distance between the neighboring pairs of rails 300 adapting to the width (measured along the lateral direction) of the solar-harvesting apparatus 100 to be installed thereon. Therefore, if all solar-harvesting apparatuses 100 to be installed have the same width, the plurality of rails 300 are mounted to the surface 304 in parallel and equidistant (i.e., uniformly spaced). In cases where the surface 304 is a sloped surface (such as a roof of a building), each rail 300 is preferably installed along a direction of same elevation (that is, one end of the rail is at the same elevation as the other end thereof).

As shown in FIGs. 19A and 19B, a pair of solar-harvesting apparatuses 100 are arranged side-by-side such that the neighboring coupling tabs (222, 236, 246A, and 246B as the case may be) of the two solar-energy harvesting apparatuses 100 are side-by-side or overlapping, with the corresponding holes 238 overlapping.

The two solar-harvesting apparatuses 100 may then be mounted to a rail 300 using a coupling tool. FIGs. 20A to 20D show an example of the coupling tool 320. As shown, the coupling tool 320 (also called "alignment plate" or "securing tool") comprises a hollow, cubical body 322 having a bottom wall 324 with two holes 326 thereon. The coupling tool 320 also comprises a pair of hollow legs 328 (in suitable form such as hollow cylinders or arc-shaped walls (also called "keyed fingers")) extending downwardly from the bottom wall 324 each at a position around a respective hole 326. The top of the body 322 is open and may be closed by a cover (not shown).

As shown in FIG. 21, after the two solar-energy harvesting apparatuses 100 are arranged side-by-side, a coupling tool 320 is applied thereto such that the two legs 328 are extended through the adjacent holes 238 at the front side of the two solar-energy harvesting apparatuses 100. A bolt 332 extends upwardly through the legs 328 to loosely engage a nut 334 to maintain a gap between the head 336 of the bolt 332 and the bottom of the coupling tabs of the two solar-harvesting apparatuses 100. As those skilled in the art will appreciate, the size of head 336 of the bolt 332 is greater than that of the hole 238. Another coupling tool 320 is also applied to the adjacent holes 238 at the rear side of the two solar-energy harvesting apparatuses 100 with the bolt 332 and nut 334 in a similar manner.

As shown in FIG. 22A, an operator (now shown) then longitudinally aligns the interface of the two engaged solar-energy harvesting apparatuses 100 with a rail 300 to slide the heads 336 of the bolts 332 into the slot 314 of the rail 300, during which the adjacent pair of downwardly extending steps 262 of the two engaged solar-energy harvesting apparatuses 100 form a downwardly facing recess receiving therein the top portion of the rail 300 to hold the two engaged solar-energy harvesting apparatuses 100 in place with proper alignment with a rail 300. Such a delimiting feature prevents the two engaged solar-energy harvesting apparatuses 100 from laterally moving away from aligning with the rail 300. Without such a delimiting feature, the operator may have to use his/her hands to hold the two engaged solar-energy harvesting apparatuses 100 to maintain the alignment (for example, when installing the solar-energy harvesting apparatuses 100 on a sloped surface as shown in FIG. 18).

The operator then fastens the nuts 334 to pull the heads 336 of the bolts 332 against the downwardly facing shoulders 316 of the slot 314 to secure the two engaged solar-energy harvesting apparatuses 100 to the rail 300. A cover 342 may then be attached to the top of the coupling tool 322 to cover the top opening thereof.

FIG. 22B is a perspective view of a portion of the two solar-energy harvesting apparatuses 100 coupled to the rail 300 using the coupling tool 320.

FIG. 23 is a perspective view of the two solar-energy harvesting apparatuses 100 coupled

to a surface 304 via a plurality of rail 300 using a plurality of the coupling tool 320. FIG. 23 also indicates that the coupling tool 300 may not be necessary for coupling a solar-energy harvesting apparatus 100 to a rail 300. In other words, a solar-energy harvesting apparatus 100 to a rail 300 simply by using bolts 332 (not shown in FIG. 23) and nuts 334, following a process similar to that described above (except without the coupling tool 320).

Thus, the structure of the solar-energy harvesting apparatus 100 provides ease of on-site installation. Moreover, the structure of the solar-energy harvesting apparatus 100 further provides ease of on-site maintenance, repair, replacement, and/or upgrade.

As shown in FIG. 23, the two solar-energy harvesting apparatuses 100 are coupled together and coupled to the rail 300A by a coupling tool 320A (including the bolt 332 and nut 334 therein (not shown)) on the front side therebetween and a coupling tool 320B (including the bolt 332 and nut 334 therein (not shown)) on the rear side therebetween. Generally, a plurality of solar-energy harvesting apparatuses 100 are coupled to a plurality of rails 300 by a plurality of bolts 332 and nuts 334, as well as one or more coupling tools 320A (if they are used) on the front side thereof, and a plurality of rails 300 by a plurality of bolts 332 and nuts 334, as well as one or more coupling tools 320A (if they are used) on the rear side thereof. The front-side bolts/nuts/coupling tools engage the coupling tabs 222 of the frame 104, the rear-side bolts/nuts/coupling tools engage the coupling tabs 236 of the hinges 232A and the coupling tabs 246A and 246B of the hinges 232B.

Therefore, as shown in FIG. 24A, when a solar-energy harvesting apparatus 100 needs maintenance, repair, replacement, and/or upgrade, an operator may decouple or otherwise remove the front-side coupling tools 320A (including the bolt 332 and nut 334 therein) (not shown) coupled to the solar-energy harvesting apparatus 100 on the two lateral sides thereof, and then lift the front side of the solar-energy harvesting apparatus 100 to rotate it upwardly (indicated by the arrow 362) with respect to the pivots (not shown) of the hinges 232A and 232B (232B not shown in FIG. 24A) to an angled position. Then, the operator may rotate the stand 252 about its pivot 256 downwardly to the stand-positioning structure 240 of the hinge 232A to secure the stand 252 in position for supporting the lifted solar-energy harvesting apparatus 100. The bottom of the solar-energy harvesting apparatus 100 is then expose to the operator to allow the operator perform the required maintenance, repair, replacement, and/or upgrade.

FIG. 24B is a perspective view of the solar-energy harvesting apparatus 100 in the lifted position. For ease of illustration, the rails 300 are not shown.

FIG. 24C is a perspective view of three solar-energy harvesting apparatus 100 wherein two of them are in the lifted position. For ease of illustration, the hinges 232A/232B and the stands 252 are not shown.

Thus, the structure of the solar-energy harvesting apparatus 100 disclosed herein provides

ease of on-site maintenance, repair, replacement, and/or upgrade, and in particular, easy access to the solar-energy harvesting apparatuses 100 located in the middle of an array of solar-energy harvesting apparatuses 100 installed on a sloped surface. In case of malfunctions, upgrading components, or replacing faulty modules, the maintenance and serviceability of the solar-energy harvesting apparatuses 100 may be simplified and expedited, thereby further enhancing the overall reliability and longevity of the solar-energy harvesting apparatuses 100 and related solar systems. This, in turn, eliminates the need for extensive dismantling or external intervention during maintenance or module replacement procedures.

In some embodiments as shown in FIG. 25, the legs 306 of a rail 300 may be mounted to a base 400 before mounted to a surface of a site. As shown in FIG. 26, the base 400 comprises a stamped galvanized steel sheet 404 and a thermoformed plastic sheet 406.

The steel sheet 404 comprises a plurality of nail or screw holes 408 for mounting to a surface, and a "stamped" or raised portion 412 having a pair of upwardly extending bolts 414.

The plastic sheet 406 comprises a correspondingly "stamped" portion 416 forming a recess (not shown) at the bottom thereof for mating to the raised portion 412 of the steel sheet 412. The stamped portion 416 of the plastic sheet 406 comprises two holes 418 for extending the bolts 414 of the steel sheet 404 therethrough.

The leg 306 comprises a foot 422 with two holes 424 for extending the bolts 414 of the steel sheet 404 therethrough so as to mount the foot 422 of the leg 306 to the stamped portion 416 of the plastic sheet 406, and to thee raised portion 412 of the steel sheet 404 after fastening a nut (not shown) onto each bolt 414.

B. HEAT TRANSFER AND THERMAL MANAGEMENT

The high-power switches and transistors in the electronic module 108 generate heat energy that needs to be properly dissipated. In addition, the PV module 102 radiates significant heat in hot sunny days that also needs to be transferred away from the energy-storage module 106 and the electronic module 108 into the surrounding environment. In some embodiments, the solar-energy harvesting apparatus 100 comprises various mechanical structures for efficient and passive heat transfer and thermal management.

As described above, in some embodiments, the energy-storage module 106 comprises a plurality of heat-conductive fins 132 on the bottom side thereof as heat sinks for heat dissipation. Similarly, the electronic module 108 also comprises a plurality of heat-conductive fins 152 on the bottom side thereof as heat sinks for heat dissipation. In some embodiments, the heat-conductive fins 132 and 152 are made of aluminum with optimized parameters such as the number of fins, fin width, and distance between fins. These optimized parameters enhance the heat dissipation capabilities of the heatsinks 132 and 152, efficiently managing the thermal load and maintaining

optimal operating temperatures for the panel.

As described above, in some embodiments, the frame 104 comprises a plurality of air vents or openings 206 on one or more sidewalls thereof, allowing airflow between the layer of the PV module 102 and the layer of the energy-storage module 106 and the electronic module 108. When the solar-energy harvesting apparatus 100 is installed on a tilted or sloped surface (such as a sloped roof), it is preferable to arrange the solar-energy harvesting apparatus 100 to a suitable orientation (for example, installing onto the rails oriented on the sloped surface as shown in FIG. 18) such that the air openings 206 on one sidewall are on the higher side of the sloped surface, and the air openings 206 on the other sidewall are on the lower side of the sloped surface, to facilitate air circulation. The air openings 206 also facilitate air circulation around the heatsink fins 132 and 152 on the energy-storage module 106 and the electronic module 108, thereby giving rise to efficient heat transfer.

In some embodiments, the energy-storage module 106 and the electronic module 108 may comprise a thermally resistive plastic cover for providing a barrier against heat transfer between the layer of the PV module 102 and the layer of the energy-storage module 106 and the electronic module 108, thereby enhancing thermal insulation and overall performance. The space between the energy-storage module 106, the electronic module 108, and the PV module 102 also facilitates airflow and in turn, provides efficient convection heat transfer.

In some embodiments, the solar-energy harvesting apparatus 100 comprises one or more radiation heat deflectors (such as one or more thin metal sheets with smooth reflective surfaces) positioned between the layer of the PV module 102 and the layer of the energy-storage module 106 and the electronic module 108. The one or more radiation heat deflectors reflect the radiation heat generated in and emitted by the PV module 102 away from the energy-storage components and electronic components in the energy-storage module 106 and the electronic module 108.

FIGs. 28A and 28B show the thermal simulation results of the solar-energy harvesting apparatus 100, or more specifically, the temperature distribution of the electronic module 108 along the cross-section line A-A shown in FIG. 27. In this example, the electronic module 108 also acts as an energy-storage module and comprises a PCB 502 implementing a multiple-port bi-directional converter (denoted a "muxConverter") and a supercapacitor 504 as the energy-storage component.

FIG. 28A shows the temperature distribution of the electronic module 108 wherein the radiation heat deflectors are used. FIG. 28B shows the temperature distribution of the electronic module 108 wherein no radiation heat deflectors are used. Clearly, the use of radiation heat deflectors gives rise to significant temperature reduction (about 6°C to 7°C) in the muxConverter PCB 502 and the energy-storage component 504.

Thus, the heat transfer and thermal management disclosed herein ensures optimized performance and longevity of the components in the solar-energy harvesting apparatus 100.

C. OPERATION OPTIMIZATION USING ARTIFICIAL INTELLIGENCE (AI)

In some embodiments, the electronic module 108 comprises one or more control circuits for management of the energy flow between the PV cells of the PV module 102, the energy-storage components of the energy-storage modules 106, and/or the output to power-consuming load and/or power grid. In some embodiments, the one or more control circuits of the electronic module 108 comprise a muxConverter which may be implemented in any suitable form such as a PCB.

In some embodiments, the electronic module 108 (for example, the muxConverter thereof) provides electricity consumption optimization. In these embodiments, the muxConverter controls the energy flow between the PV module 102, the energy-storage modules 106, and the output to power-consuming load and/or power grid, and uses an artificial intelligence (AI) engine (such as using a machine learning (ML) engine) to optimize the electricity consumption cost for electricity users.

Of course, those skilled in the art will appreciate that, in other embodiments, the optimization of the electricity consumption cost may be performed by any other suitable components or devices that may be connected to the solar-energy harvesting apparatus 100 or the PV module 102 and the energy-storage modules 106 thereof via suitable wired and/or wireless methods.

For example, in some embodiments, the optimization of the electricity consumption cost may be performed by a control module of the solar-energy harvesting apparatus 100 functionally connected to the PV module 102 and the energy-storage modules 106 thereof via suitable wired and/or wireless methods. The control module may comprise one or more processors functionally connected to one or more computer-readable storage media or devices to execute computer-executable instructions stored therein to act as the AI engine (such as the ML engine) and perform the optimization of the electricity consumption cost.

In some embodiments, the optimization of the electricity consumption cost may be performed by a control device physically separated from the solar-energy harvesting apparatus 100 and functionally connected to the solar-energy harvesting apparatus 100 via suitable wired and/or wireless methods. The control device may comprise one or more processors functionally connected to one or more computer-readable storage media or devices to execute computer-executable instructions stored therein to act as the AI engine (such as the ML engine) and perform the optimization of the electricity consumption cost.

In some embodiments, the ML engine uses the following cost function:

$$CostFunc(d,m) = \sum_{h=1}^{24} A(h,d,m) \times B(h,d,m) \quad (1)$$

where A and B are functions of the electricity cost per watt-hour (Wh) and the Wh energy usage at the hour h of day d and month m, respectively. Function A depends on the geographical location of the solar system (which may be a solar system using the solar-energy harvesting apparatus 100 disclosed herein) and may be obtained from the utility services covering the region. Function B depends on the amount of solar energy harvesting $PV(h, d, m)$, the amount of stored energy $Storage(h, d, m)$, and the consumption $Load(h, d, m)$ by the electricity user at that time, specifically,

$$B(h, d, m) = Load(h,d,m) + Storage(h,d,m) - PV(h, d, m) \quad (2)$$

By using the cost function (1), the ML engine predicts the energy consumption by the customers to calculate function *Load*. This is accomplished through processing the historical data from electricity usage by the specific customers collected using the energy meter in the system. Function *PV* is also predicted using a third-party weather pattern data and solar radiation pattern based on the altitude and latitude of the geographical site of installation. In addition, the ML engine also accurately predicts solar harvesting energy using the historical data of solar harvesting energy collected from previous years of operation in such a way that the prediction becomes increasingly more accurate in time. Thus, by using the cost function (1) with the predictions of *Load* and *PV*, the ML engine may adjust the time of charging and discharging the energy-storage components of the energy-storage modules 106 to minimize the electricity cost.

Those skilled in the art will appreciate that the AI/ML engine disclosed herein may also be used in other solar-energy harvesting apparatuses, solar panels, and/or solar-energy harvesting systems.

FIGs. 29A to 29E show an example of the electricity costs for a single day using various systems.

FIGs. 29A and 29B shows the electricity rates offered by a utility company, showing the off-peak, mid-peak, and on peak time ranges for weekdays (FIG. 29A) and weekends (FIG. 29B), wherein the off-peak electricity rate is 7.4 cents per kilowatt (kW) hour (h), the mid-peak electricity rate is 10.2 cents/kWh, and the on-peak electricity rate is 15.1 cents/kWh.

FIG. 29C illustrates a typical load entirely supplied by the power grid in absence of any solar system. The electricity rate for a single day is 21.5 cents/kWpv. With electricity consumption of 8kWpv/day, the electricity cost is $8.86/day.

FIG. 29D illustrates a typical load supplied by PV panels without any energy storage system. The PV panels are controlled by the AI/ML engine disclosed herein. The electricity rate for a single day is 21.5 cents/kWpv. With electricity consumption of 8kWpv/day, the electricity cost is reduced to $1.72/day.

FIG. 29E illustrates a typical load supplied by PV panels and energy storage. The PV panels and energy storage are controlled by the AI/ML engine disclosed herein. The electricity rate for a single day is 9.9 cents/kWpv. With electricity consumption of 8kWpv/day, the electricity cost is reduced to $0.79/day.

The cost savings as shown in FIGs. 29D and 29E are obtained by offsetting the power-grid usage from on-peak slots to the off-peak slots, through proper timing of charging and discharging the energy storage system using the AI/ML engine disclosed herein.

D. POWER SYSTEM AND DEVICE AUTO-IDENTIFICATION

Power systems have been widely used for powering energy-consumption objects such as an array of building blocks or units. An example of a power system is a light-emitting diode (LED) lighting system for growing plants (also called a grow-light system) or a street light system in which LED lighting modules are used. The power system may comprise one or more solar-energy harvesting apparatus 100 and/or other suitable solar panels for generating electricity. In a power system, the knowledge of the system configuration and the location of individual units is important for performance monitoring, fault detection, and troubleshooting.

In conventionally power system (whether for power plants or for residential use), solar panels are connected in series in a so-called *string topology* to produce a DC of high voltage which is subsequently converted to an AC using an inverter. However, this string-topology based configuration lacks sufficient control over the electrical outputs of individual solar panels, and as a result, the energy extraction therefrom cannot be maximized using, for example, maximum power point tracking (MPPT) algorithms. Consequently, the overall efficiency of energy conversion is limited by the solar panel having poorest efficiency in the solar-panel string. Even in ideal cases, there are tolerances in the efficiency of solar panels due to manufacturing imperfections which limit the overall efficiency. In practical cases, any damage or shadowing due to clouds, roof structures, surrounding landscape, snow covering, animal dropping, and/or the like, on even one solar panel may greatly reduce the overall efficiency of the entire power system.

To address this issue, solar energy industry is going towards electronic topologies that have control at the individual PV-panel level. *String optimizers* and *microinverters* are two common examples of the topologies where energy extraction from the individual PV panels can be maximized. Distributed circuitry at the panel level in these topologies necessitates device recognition within an array system for system configuration, fault detection, and troubleshooting. Traditionally, bar codes or quick response (QR) codes are utilized for device identification. However, these methods entail cumbersome manual works in installation and may be impractical for solar power plants having a large number of PV panels.

In some embodiments, a power system having an array of solar panels may use an auto-

identification (AID) method for facilitating device recognition and configuration. This method allows a master unit to identify devices connected thereto, including the number of devices connected, their configuration, geographical locations, the order of the connection, and/or the like. In AID, the master unit initiates a signal transmitted to the connected devices. In response, each device sequentially provides a unique identifier, such as a serial number or any other suitable unique identifier that differentiates it from other devices. Upon receiving the responses from the devices, the master unit understands the number of devices connected as well as their configuration in the system, which enables device control, performance monitoring, and troubleshooting at individual panel level. The AID method may also automatically map the physical location of each device in the array based on a device-installation blueprint.

FIG. 30 shows a power system 600 deployed in a site 602 such as a building and using the AID method for device recognition and configuration, according to some embodiments of this disclosure. The power system 600 comprises a master unit 604, one or more intermediate units or devices 606 such as solar panels, and an end unit 608. As shown in FIG. 31, the master unit 604, the plurality of devices 606 (also denoted as units U_1 to U_n), and the end unit 608 are connected sequentially or in series, beginning from the master unit 604 and ending by the end unit 608, thereby forming a master-slave model for effective communication and coordination therebetween.

As shown in FIG. 32, in these embodiments, each intermediate unit or device 606 comprises a circuit for AID, which comprises a microcontroller (μC) 620 connecting to a FDBK port, a communication port having a first communication terminal COMH and a second communication terminal COML, a PREV port, and a NEXT port. The FDBK port, the PREV port, and the NEXT port of each intermediate unit 606 are in a LOW state by default (for example, before the AID method starts).

As shown in FIG. 33, the master unit 604 comprises a circuit for AID which comprises a μC (not shown) connecting to a feedback port FDBK, a communication port having a first communication terminal COML and a second communication terminal COMH, and a next port (NEXT).

The FDBK port of the master unit 604 is connected to a feedback channel 622 (which in these embodiments is a feedback line). The communication port of the master unit 604 is connected to a communication channel having a first communication line (COMH) 624 and a second communication line (COML) 626 such that the COMH terminal of the master unit 604 is connected to the COMH line 624 and the COML terminal of the master unit 604 is connected to the COML line 626. The NEXT port of the master unit 604 is connected to a previous port (PREV) of the first intermediate unit U_1.

The end unit 608 comprises circuit for AID which comprises a μC (not shown) connecting

to a FDBK port, a communication port having a first communication terminal COMH and a second communication terminal COML, and a PREV port.

The FDBK port of the end unit 608 is connected to the feedback line 622. The communication port of the end unit 608 is connected to the communication channel such that the COMH terminal of the end unit 608 is connected to the COMH line 624 and the COML terminal of the end unit 608 is connected to the COML line 626. The PREV port of the end unit 608 is connected to a NEXT port of the last intermediate unit U_n.

The FDBK port of each intermediate unit U_i (i = 1, 2, …, n) is connected to the feedback line 622. The communication port of each intermediate unit 606 is connected to the communication channel such that the COMH terminal of the end unit 608 is connected to the COMH line 624 and the COML terminal of the end unit 608 is connected to the COML line 626. The PREV port of each intermediate unit 606 is connected to the NEXT port of the previous unit (which is the master unit 604 if the intermediate unit is the first intermediate unit U_1, and is the previous intermediate unit U_{i-1} if i > 1). The NEXT port of each intermediate unit 606 is connected to the PREV port of the next unit (which is the next intermediate unit U_{i+1} if i < n, and is the end unit 608 if i = n).

In some embodiments, when the AID method is performed, the master unit 604 sets its NEXT port to a HIGH state, which sets the PREV port of the first device U_1 to the HIGH state and triggers the first device U_1 to report a unique identifier (ID; such as a serial number or any other unique identifier that sets it apart from other devices or units) to the master unit 604 through the communication channel (e.g., the communication lines 624 and 626). Then, the first device U_1 sets its NEXT port (and thus the PREV port of the next device U_2) to the HIGH state.

Generally, when the PREV port of the i-th intermediate unit U_i (i = 1, 2, …, n) is set to the HIGH state, the i-th device U_i reports its unique ID to the master unit 604 through the communication channel, and sets its NEXT port (and thus the PREV port of the next unit (being the next intermediate unit U_{i+1} or the end unit 608)) to the HIGH state to trigger the next intermediate unit U_{i+1} to reports its unique ID to the master unit 604 through the communication channel. Thus, each intermediate unit sequentially reports its unique ID until the PREV port of the end unit 608 is set to the HIGH state. Then, the end unit 408 sets its FDBK port and thus the PDBK line 622 to the HIGH state, informing the master unit 604 that all devices 606 in the chain have registered their unique IDs and the AID method is completed.

Upon receiving the responses from the intermediate units 606, the master unit 604 understands the number of intermediate units connected in the array and their configuration, which, in turn, enables device control, performance monitoring, and troubleshooting at individual unit

level. Given a prior blueprint of the installation, AID can automatically map the physical location of each device in the array.

In some embodiments, when the AID method is performed, the master unit 604 sets its NEXT port to a HIGH state, which sets the PREV port of the first device U_1 to the HIGH state and triggers the first device U_1 to request a unique identifier (ID; which may be a unique number) from the master unit 604 through the communication channel (e.g., the communication lines 624 and 626) if the first device U_1 has not been assigned a unique ID. In response, the master unit 604 sends a new ID to U_1 through the communication channel. Once the first device U_1 receives and registers the unique ID, the first device U_1 acknowledges the safe receipt through the communication channel and sets its NEXT port (and thus the PREV port of the next device U_2) to the HIGH state.

If the first device U_1 has been assigned a unique ID, the first device U_1 sets its NEXT port (and thus the PREV port of the next device U_2) to the HIGH state.

Generally, when the PREV port of the i-th intermediate unit U_i ($i = 1, 2, \ldots, n$) is set to the HIGH state, and if the i-th device U_i has not been assigned a unique ID, the i-th device U_i requests a unique ID from the master unit 604 through the communication channel. In response, the master unit 604 sends a new ID through the communication channel to the i-th device U_i. Once the i-th device U_i receives and registers the unique ID, the i-th device U_i acknowledges the safe receipt through the communication channel and sets its NEXT port (and thus the PREV port of the next unit (being the next intermediate unit U_{i+1} or the end unit 608)) to the HIGH state.

If the i-th device U_i has been assigned a unique ID, the i-th device U_i sets NEXT 636 (and thus PREV 628 of its next device U_{i+1}) to the HIGH state.

This process repeats through the chain until reaching the end unit 608 which sets its FDBK port and thus the PDBK line 622 to the HIGH state, informing the master unit 604 that all devices 606 in the chain have registered their unique IDs and the AID method is completed. The master unit 604 thus understands the number of intermediate units connected in the array and their configuration, which, in turn, enables device control, performance monitoring, and troubleshooting at individual unit level. Given a prior blueprint of the installation, AID can automatically map the physical location of each device in the array.

The AID method ensures a robust and reliable system configuration within this master-slave model. It facilitates accurate communication, proper coordination, and streamlined operations, contributing to the overall efficiency and effectiveness of the power system. The AID method is pivotal establishment and re-establishment of the system configuration in the initial runs, during and following power outages, and upon user's requests. Given the blueprint of the power system 600, the AID method may accurately identify the geographical location of the devices 606.

Those skilled in the art will appreciate that various alternative embodiments are readily available. For example, in some embodiments, an energy-storage module 106 and an electronic module 108 may be a same module. In other words, such a module may receive in the enclosure thereof one or more energy-storage components and one or more control circuits 144.

In some embodiments, the solar-energy harvesting apparatus 100 may not comprise any energy-storage module 106. Rather, the energy-storage components are physically separated from the solar-energy harvesting apparatus 100 and are functionally connected thereto.

In some embodiments, the solar-energy harvesting apparatus 100 may not comprise any electronic module 108. Rather, the control circuits 114 are physically separated from the solar-energy harvesting apparatus 100 and are functionally connected thereto.

In some embodiments, the frame 104 may only comprise one hinge such as the hinge 232A or the hinge 232B.

In some embodiments, the stand 252, after rotating downwardly, may be secured to the rail 300. In these embodiments, the hinge 232A may not comprise a stand-positioning structure 240.

In above embodiments, the coupling structures of the energy-harvesting apparatus 100 are in the form of coupling tabs. In some embodiments, the coupling structures of the energy-harvesting apparatus 100 may be in any other suitable forms such as suitable locking structures.

In some embodiments, the energy-harvesting apparatus 100 may not comprise the two coupling structures 222.

In above embodiments, the energy-harvesting apparatus 100, when mounted on top of the rails 300, may rotate upwardly from the position resting on the rails 300, and rotating downwardly back to that position. In embodiments as shown in FIGs. 34A and 34B, the energy-harvesting apparatus 100 may be mounted to a recess on the bottom of the rails in a manner similar to above-described mounting method. The energy-harvesting apparatus 100 may rotate downwardly from the position resting on the rails 300, and rotate upwardly back to that position.

Although embodiments have been described above with reference to the accompanying drawings, those of skill in the art will appreciate that variations and modifications may be made without departing from the scope thereof as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A solar-energy harvesting apparatus comprising:

a base structure;

a photovoltaic (PV) module demountably coupled to a first side of the base structure; and

one or more electronic modules and/or one or more energy-storage modules demountably coupled to a second side of the base structure.

2. The solar-energy harvesting apparatus of claim 1, wherein the first side is a top side, and the second side is a bottom side.

3. The solar-energy harvesting apparatus of claim 1 or 2, wherein the base structure is made of injection moldable NORYL GFN1 resin with 10% glass reinforced blend of polyphenylene ether and polystyrene.

4. The solar-energy harvesting apparatus of any one of claims 1 to 3, wherein the base structure comprises a sealing groove on the first side thereof for receiving a sealing component therein for sealably engaging the PV module and preventing water leaking to the one or more electronic modules and/or one or more energy-storage modules.

5. The solar-energy harvesting apparatus of any one of claims 1 to 4, wherein the base structure comprises a first coupling structure and a second coupling structure on two laterally opposite sides of the base structure positioned at or in proximity with a rear side thereof; and

wherein the first and second coupling structures are positioned such that, when two solar-energy harvesting apparatuses are arranged laterally side-by-side, the first coupling structure of a first one of the two solar-energy harvesting apparatuses overlaps with or side-by-side with the second coupling structure of a second one of the two solar-energy harvesting apparatuses.

6. The solar-energy harvesting apparatus of claim 5, wherein, when the two solar-energy harvesting apparatuses are arranged laterally side-by-side, the first and second coupling structures are securable by a securing apparatus;

wherein the securing apparatus comprises two hollow legs for extending through holes on the overlapped or side-by-side coupling structures of the two solar-energy harvesting apparatuses; and

wherein each hollow leg of the securing apparatus comprises a bore for receiving a nut extending therethrough for securing the two solar-energy harvesting apparatuses on a securing base.

7. The solar-energy harvesting apparatus of claim 6, wherein, when the securing apparatus comprises a hollow body having an open top, a bottom wall, and two holes on the bottom wall thereof; and

wherein each hollow leg is extended outwardly from the bottom wall of the hollow body with the bore of the hollow leg connected to a respective one of the two holes on the bottom wall of the hollow body.

8. The solar-energy harvesting apparatus of claim 7, wherein, when the securing apparatus comprises a cover engageable to the open top of the hollow body.

9. The solar-energy harvesting apparatus of any one of claims 6 to 8, wherein the securing base is a rail; and

wherein the rail comprises a first elongated slot having two shoulders on opposite sides thereof for sliding in and engaging therewith a head of the nut for securing the two solar-energy harvesting apparatuses on a securing base.

10. The solar-energy harvesting apparatus of claim 9, wherein the base structure comprises a pair of downwardly extending and laterally outwardly facing steps on or in proximity with the laterally opposite sides of the base structure, such that, when the two solar-energy harvesting apparatuses are arranged side-by-side and positioned onto the rail, the adjacent steps of the two solar-energy harvesting apparatuses form a delimiting structure for delimiting the rail therebetween.

11. The solar-energy harvesting apparatus of claim 9, wherein the rail comprises a second elongated slot on a sidewall thereof, the second elongated slot comprising two shoulders on opposite sides thereof for sliding in and engaging therewith a head of a nut for securing the rail to a leg.

12. The solar-energy harvesting apparatus of any one of claims 5 to 11, wherein the base structure comprises a third coupling structure and a fourth coupling structure on the two laterally opposite sides of the base structure positioned at or in proximity with a front side thereof; and

wherein the third and fourth coupling structures are positioned such that, when the two solar-energy harvesting apparatuses are arranged laterally side-by-side, the third coupling structure of the first one of the two solar-energy harvesting apparatuses overlaps with or side-by-side with the fourth coupling structure of the second one of the two solar-energy harvesting apparatuses.

13. The solar-energy harvesting apparatus of any one of claims 5 to 12, wherein each of the first and second coupling structures is coupled to the base structure via a hinge such that the solar-energy harvesting apparatus is pivotable around the hinge with respect to the first and second coupling structures.

14. The solar-energy harvesting apparatus of claim 13, wherein the first coupling structure is on an arm, and the arm is coupled to the base structure via the hinge; and

wherein the arm is receivable in an elongated recess of the base structure.

15. The solar-energy harvesting apparatus of claim 14, wherein the elongated recess of the base structure receives therein a stand; and

wherein the stand is rotatable out of the elongated recess of the base structure for supporting the solar-energy harvesting apparatus.

16. The solar-energy harvesting apparatus of claim 15, wherein the arm comprises a notch; and

wherein the stand comprises a tip engageable with the notch when the stand and the arm are rotated out of the elongated recess of the base structure.

17. The solar-energy harvesting apparatus of any one of claims 1 to 16, wherein the base structure comprises a plurality of air vents on one or more sidewalls thereof, and a plurality of tabs each positioned beside one of the plurality of air vents for guiding the airflow.

18. The solar-energy harvesting apparatus of any one of claims 1 to 17, wherein each of the one or more electronic modules and the one or more energy-storage modules comprises:

an enclosure having a plurality of heat-conductive fins on the second side thereof for heat dissipation;

a cover coupled to the first side of the enclosure for closing the enclosure;

an electromagnetic shield layer 126 attached to an interior side of the cover for shielding electromagnetic interferences; and

a heat deflector coupled to an exterior side of the cover.

19. The solar-energy harvesting apparatus of claim 18, wherein the cover comprises a plurality of spacers on the exterior side thereof for supporting the heat deflector and maintaining a gap

between the heat deflector and the cover.

20. The solar-energy harvesting apparatus of claim 18, wherein the cover is a thermal-resistive cover.

21. The solar-energy harvesting apparatus of any one of claims 1 to 20, wherein the one or more electronic modules comprise one or more control circuits for managing energy flow between the PV module, the one or more energy-storage modules, and output of the solar-energy harvesting apparatus using an artificial intelligence (AI) engine to optimize electricity consumption cost for an electricity user of the solar-energy harvesting apparatus.

22. The solar-energy harvesting apparatus of claim 21, wherein the AI engine comprises a machine learning (ML) engine with a cost function:

$$CostFunc(d,m) = \sum_{h=1}^{24} A(h,d,m) \times B(h,d,m)$$

where A is a function of the electricity-consumption cost per watt-hour (Wh) at a time of hour h of day d and month m, and function B is a function of the Wh energy usage and

$$B(h, d, m) = Load(h,d,m) + Storage(h,d,m) - PV(h, d, m)$$

where $Load(h, d, m)$ is electricity consumption of the one or more electricity-consuming devices at the time, $Storage(h, d, m)$ is an amount of stored energy of the one or more energy-storage modules, and $PV(h, d, m)$ is an amount of solar energy harvested by the one or more PV modules.

23. The solar-energy harvesting apparatus of claim 22, wherein the ML engine is configured for predicting the energy consumption by the electricity user and the amount of solar energy harvesting for adjust times of charging and discharging the one or more energy-storage modules to minimize the cost function.

24. A computerized method comprising:

minimizing electricity-consumption cost of a system using an artificial intelligence method.

25. The computerized method of claim 24, wherein the system comprises: one or more PV modules, one or more energy-storage modules, and one or more electricity-consuming devices; and

wherein said minimizing electricity-consumption cost using the artificial intelligence method comprises:

minimizing the electricity-consumption cost using a machine learning method with a cost function:

$$CostFunc(d,m) = \sum_{h=1}^{24} A(h,d,m) \times B(h,d,m)$$

where A is a function of the electricity-consumption cost per watt-hour (Wh) at a time of hour h of day d and month m, and function B is a function of the Wh energy usage and

$$B(h, d, m) = Load(h,d,m) + Storage(h,d,m) - PV(h, d, m)$$

where $Load(h, d, m)$ is electricity consumption of the one or more electricity-consuming devices at the time, $Storage(h, d, m)$ is an amount of stored energy of the one or more energy-storage modules, and $PV(h, d, m)$ is an amount of solar energy harvested by the one or more PV modules.

26. The computerized method of claim 24 or 25 further comprising:

controlling time of charging and discharging the one or more energy-storage modules based on said minimization.

27. The computerized method of claim 26 dependent from claim 25, wherein said optimizing electricity-consumption cost using the artificial intelligence method comprises:

predicting $Load(h, d, m)$ based on historical data of electricity usage;

28. The computerized method of claim 27, wherein said optimizing electricity-consumption cost using the artificial intelligence method comprises:

predicting $PV(h, d, m)$ based on:

a weather pattern and a solar radiation pattern,

historical data of harvested solar energy, or

a combination thereof.

29. The computerized method of claim 27, wherein said optimizing electricity-consumption cost using the artificial intelligence method comprises:

predicting $PV(h, d, m)$ based on a weather pattern and a solar radiation pattern.

30. One or more processors functionally connected to one or more computer-readable storage media for performing the method of any one of claims 24 to 29.

31. One or more non-transitory computer-readable storage media comprising computer-executable instructions, wherein the instructions, when executed, cause one or more circuits to perform the method of any one of claims 24 to 29.

32. A system comprising:

a plurality of units comprising a master unit, one or more intermediate units U_1, …, U_n, and an end unit connected in series beginning from the master unit and ending by the end unit, where $n \geq 1$ is an integer;

wherein the i-th intermediate unit (i = 1, 2, …, n) is configured for:

receiving a triggering signal from an immediately previous one of the plurality of units, the immediately previous one of the plurality of units being the master unit if i = 1, or being the (i-1)-th unit if i > 1,

communicating with the master unit via a communication channel regarding a unique identifier of the i-th intermediate unit, and

sending the triggering signal to an immediately next one of the plurality of units, the immediately next one of the plurality of units being the end unit if i = n, or being the (i+1)-th unit if i < n.

33. The system of claim 32, wherein said communicating with the master unit regarding the unique identifier of the i-th intermediate unit comprises:

sending a request to the master unit,

receiving the unique identifier from the master unit; or

wherein said communicating with the master unit regarding the ID of the i-th intermediate unit comprises:

reporting the unique identifier to the master unit.

34. The system of claim 32 or 33, wherein the i-th intermediate unit is further configured for:

sending an acknowledgement to the master unit via the communication channel after receiving the unique identifier from the master unit.

35. The system of any one of claims claim 32 to 34, wherein the end unit is configured for:

receiving the trigger signal; and

sending a feedback signal via the feedback channel.

36. The system of any one of claims 32 to 35, wherein each of the plurality of units comprises:

a feedback port connecting to a feedback channel, and

a communication port connecting to the communication channel;

wherein the master unit further comprises a next port for sending the triggering signal;

wherein the end unit further comprise a previous port for receiving the triggering signal;

wherein each of the one or more intermediate units further comprises:

a previous port for receiving the triggering signal, and

a next port for sending the triggering signal; and

wherein the previous port of the i-th intermediate unit is connected to the next port of the immediately previous one of the plurality of units, and the next port of the i-th intermediate unit is connected to the previous port of the immediately next one of the plurality of units.

37. The system of claim 36, wherein the communication channel comprises a first communication line and a second communication line; and

wherein the communication port of each of the plurality of units comprises a first communication terminal connecting to the first communication line, and a second communication terminal connecting to the second communication line.

38. The system of claim 36 or 37, wherein the feedback channel comprises a feedback line; and

wherein the feedback port of each of the plurality of units is connected to the feedback line.

39. The system of any one of claims 36 to 38 dependent from claim 35, wherein said sending the trigger signal performed by the i-th intermediate unit comprises:

changing the next port from a first state to a second state;

wherein said receiving the trigger signal performed by the i-th intermediate unit or by the end unit comprises:

detecting that the previous port is changed from the first state to the second state; and

wherein said sending the feedback signal performed by the end unit comprises:

changing the feedback port from a third state to a fourth state.

40. The system of claim 39, wherein the first state is a LOW state, the second state is a HIGH state, the third state is the LOW state, and the fourth state is the HIGH state.