

SYSTEMS FOR CONTROLLING PLASMA REACTORS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to plasma generators, and more particularly to systems
5 for controlling a large number of plasma reactors.

2. Discussion of the Related Art

[0002] In recent years, microwave technology has been applied to generate various types of plasma. Typically, a microwave discharge, which is used as a plasma source, is achieved by coupling microwave energy into a discharge chamber containing gas to be processed. FIG. 1
10 shows a schematic diagram of a conventional plasma generating system. As depicted, the conventional plasma generating system **10** includes: a programmable logic controller (PLC) **12**; a plurality of digital input-output/analogue input-output (DIO/AIO) modules **14a – 14n**; and a plurality of reactor systems **16a – 16n** that include a plurality of power supplies **17a – 17n** and a plurality of reactors **18a – 18n**. The DIO/AIO modules **14a – 14n** are connected to the PLC **12**
15 and the reactors **18a – 18n** via the cable harnesses **15a – 15n**, respectively. The PLC **12** is also connected to the plurality of power supplies **17a-17n** via the cables **13a – 13n**, where each power supply provides electrical power to a corresponding reactor.

[0003] Typically, each cable harness (e.g. **15a**) includes a plurality of electrical wires, where each wire is connected to the DIO/AIO module **14a** and a sensor/component of the reactor **18a**.
20 For instance, the reactor **18a** includes sensors that transmit electrical signals associate with measured physical quantities to the DIO/AIO module **14a**, and the DIO/AIO device **14a** in turn processes the signals and transmits the processed signals to the PLC **12**. To increase the throughput of the plasma generating system **10**, the number of reactor systems **16a – 16n** may be increased, resulting in significant increase in the total number of electrical wires in the cable
25 harnesses **15a – 15n** as well as the cables **13a – 13n**. The increase in the number of wires/cables decreases the reliability in cable connections, raises safety issues and increases the installation/maintenance costs.

[0004] Furthermore, the plasma generating system **10** has a centralized control architecture, i.e., the PLC **12** simultaneously controls/monitors the power supplies **17a – 17n** as well as multiple components of the reactors **18a – 18n** via the DIO/AIO modules **14a – 14n**. Typically, the PLC **12** contains a central processing unit (CPU), random access memory (RAM) and
5 electrically erasable programmable read only memory (EEPROM), and the CPU executes the program stored in the EEPROM and temporary data and code are stored in RAM. As the number of reactor systems **16a – 16n** increases, the latency in command and control between the PLC **12** and reactor systems **16a – 16n** increases, and, when the number of reactor systems **16a – 16n** exceeds a certain threshold value, the required computational power to control the plasma
10 generating system **10** reaches beyond the maximum capacity of the PLC **12**, causing the latency to become unacceptable. Thus, in the conventional systems, the computational power, digital/analog inputs/outputs, and electrical harnesses need to scale up to meet functional and safety requirements, resulting in large, expensive, and inherently less reliable systems.

[0005] As such, there is a need for a system for controlling a large number of plasma reactors
15 that has enhanced scalability, safety and reliability without compromising the installation/maintenance costs.

SUMMARY OF THE INVENTION

[0006] According to one aspect of the present invention, a plasma generating system that includes: a microwave generator for generating microwave energy; and a power supply for
20 providing electrical power to the microwave generator and including a controller. The controller includes: at least one microprocessor; and a module communicatively coupled to the at least one processor and including at least one of digital input-output (DIO) and analogue input-output (AIO).

[0007] According to another aspect of the present invention, a plasma generating system that
25 includes: a programmable logic controller (PLC) and a plurality of reactor systems coupled to the PLC by a daisy chain network. Each of the plurality of reactor systems include: a microwave generator for generating microwave energy; and a power supply for providing electrical power to the microwave generator and including a controller, where the controller comprises: at least one

microprocessor; and a module communicatively coupled to the at least one processor and including at least one of digital input-output (DIO) and analogue input-output (AIO).

BRIEF DESCRIPTION OF THE DRAWINGS

- 5 [0008] Figure 1 ("FIG. 1") shows a schematic diagram of a conventional plasma generating system.
- [0009] FIG. 2 shows a schematic diagram of a plasma generating system according to embodiments of the present disclosure.
- [0010] FIG. 3 shows a schematic diagram of an exemplary reactor system having a controller according to embodiments of the present disclosure.
- 10 [0011] FIG. 4 shows a schematic diagram of an exemplary reactor system having a controller according to embodiments of the present disclosure.
- [0012] FIG. 5 shows a cross sectional view of the plasma chamber in FIG. 4, taken along the line 5-5, according to embodiments of the present disclosure.
- 15 [0013] FIG. 6 shows a perspective view of a forward flow inlet according to embodiments of the present disclosure.
- [0014] FIG. 7 shows a cross sectional view of the forward flow inlet in FIG. 6, taken along the line 7-7, according to embodiments of the present disclosure.
- [0015] FIG. 8 shows a perspective view of a reverse flow inlet according to embodiments of the present disclosure.
- 20 [0016] FIG. 9 shows a cross sectional view of the reverse flow inlet in FIG. 5, taken along the line 9-9, according to embodiments of the present disclosure.
- [0017] FIG. 10 shows a perspective view of an inner vortex flow according to embodiments of the present disclosure.
- 25 [0018] FIG. 11 shows a perspective view of an outer vortex flow according to embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] In the following description, for purposes of explanation, specific details are set forth in order to provide an understanding of the disclosure. It will be apparent, however, to one skilled in the art that the disclosure can be practiced without these details. Furthermore, one skilled in the art will recognize that embodiments of the present disclosure, described below, may be implemented in a variety of ways.

[0020] Components, or modules, shown in diagrams are illustrative of exemplary embodiments of the disclosure and are meant to avoid obscuring the disclosure. It shall also be understood that throughout this discussion that components may be described as separate functional units, which may comprise sub-units, but those skilled in the art will recognize that various components, or portions thereof, may be divided into separate components or may be integrated together, including integrated within a single system or component. It should be noted that functions or operations discussed herein may be implemented as components.

[0021] Reference in the specification to “one embodiment,” “preferred embodiment,” “an embodiment,” or “embodiments” means that a particular feature, structure, characteristic, or function described in connection with the embodiment is included in at least one embodiment of the disclosure and may be in more than one embodiment. Also, the appearances of the above-noted phrases in various places in the specification are not necessarily all referring to the same embodiment or embodiments.

[0022] The use of certain terms in various places in the specification is for illustration and should not be construed as limiting. The terms “include,” “including,” “comprise,” and “comprising” shall be understood to be open terms and any lists the follow are examples and not meant to be limited to the listed items.

[0023] FIG. 2 shows a schematic diagram of a plasma generating system **20** according to embodiments of the present disclosure. FIG. 3 shows a schematic diagram of an exemplary reactor system **24a** according to embodiments of the present disclosure. FIG. 4 shows a schematic diagram of an exemplary reactor system **24a** according to embodiments of the present disclosure. Hereinafter, the reactor system **24a** is illustrated as a system for generating plasma

using microwave energy, even though the reactor system **24a** may generate plasma using other source of energy.

[0024] In embodiments, the plasma generating system **20** includes: a PLC system (or shortly PLC) **22**; and a plurality of reactor systems **24a – 24n**. In some cases, to increase the throughput
5 of the system, the plurality of reactor systems **24a – 24n** may number in the tens, hundreds or more. In embodiment, the reactor systems **24a – 24n** are daisy chained to the PLC **22** by a cable **26**, such as Category 6 Ethernet cable, and communicate to the PLC **22** using a suitable communication protocol, such as EtherNet/IP or other suitable process automation protocols.

[0025] In embodiments, the reactor system **24a** includes; a power supply **30** having a reactor
10 controller; sensor and monitoring systems **32**; a magnetron **34** for generating microwave energy; a waveguide **36** through which the microwave energy generated by the magnetron **34** flows; an impedance matching network **38** coupled to the waveguide **36** and configured to reduce the amount of microwave energy retrogressing toward the magnetron **34**; an ignition system **40** for igniting the plasma, and plasma chamber **42**. In embodiments, the power supply **30** is
15 communicatively coupled to the rest of the components in the reactor system **24a**. It is noted that FIG. 3 does not show the exhaustive list of components of the reactor system **24a**; instead, the components of the reactor system **24a** are divided into blocks for the purpose of illustration.

[0026] In embodiments, the sensor and monitoring system **32** includes one or more sensors for generating electrical signals associated with operation of the reactor system **24a**. For
20 instance, the sensor and monitoring system **32** includes one or more sensors, such as **190a – 190c**, for measuring thermophysical quantities, such as pressure and temperature, and one or more monitoring devices that monitor the plasma health using the signals from one or more sensors. In another example, the sensor and monitoring system **32** includes one or more flow rate sensors, such as **190d** (and **190e**), for measuring flow rate of the gas flowing through the gas
25 line **128** (and **124**) from the gas tank **130** (and **126**). In embodiments, the sensor **190d** (and **190e**) and a gas servo valve for controlling the flow rate may form an integral body.
(Hereinafter, the reference numeral **190d** (and **190e**) is referred to as both sensor and gas servo valve.) In yet another example, the sensor and monitoring system **32** includes an optical sensor

that measures the intensity of light from the plasma at various wavelength ranges and monitors the plasma health.

5 [0027] As depicted in FIG. 4, the power supply **30** includes a reactor controller **174** that controls and monitors the components of the reactor system **24a**. In embodiments, the reactor controller **174** includes; at least one microprocessor (μ -processor) **176**; a DIO/AIO module **178** communicatively coupled to the μ -processor **176**; and a memory **180** communicatively coupled to the μ -processor **176**. In embodiments, the DIO/AIO communicates data with various components **32 – 42** in FIG. 3 as well as the μ -processor **176**.

10 [0028] In embodiments, the DIO/AIO module **178** includes one or more DIO devices (or simply DIOs) and/or one or more AIO devices (or simply AIOs), where the DIOs and AIOs are preferably integrated into a printed circuit board, to thereby reduce the cost, size and complexity of the system wiring harness. In embodiments, each DIO device (or AIO) is an interface that relays digital (or analog) signals from sensors, transducers and mechanical devices to other electronic circuits and devices.

15 [0029] Unlike in the conventional system **10** where the PLC (which is also referred to as “central controller”) **12** is directly connected to and directly communicates data to the DIO/AIO modules **14a – 14n**, the PLC **22** is not directly connected to DIO/AIO modules **178**; instead, the PLC **22** is directly connected only to the power supply **30** of each reactor system (e.g. **24a**) by the daisy chain network of communication cables **26**. Thus, unlike the conventional PLC **12** that operates as a central control system, the PLC **22** and the power supplies **30** form a distributed control system/architecture. In embodiments, since the DIO/AIO module **178** is not directly connected to the PLC **22**, the number of wires/cables connected to the PLC **22** does not increase as the number of reactor systems **24a – 24n** increases, i.e., the reliability in cable connections is not affected by the number of reactor systems **24a – 24n**.

25 [0030] In embodiments, the distributed control architecture allows the control and monitoring responsibilities to be off loaded from the PLC **22** to the reactor controller (which is also referred to as local controller) **174** that resides in the power supply **30** of each reactor system (e.g. **24a**). This distributed control architecture has the advantages of reducing the latency in command and control between the reactor systems **24a – 24n** and the PLC **22** since the local controller **174** is

tasked with monitoring and controlling only one reactor system rather than having the PLC 12 manage hundreds of reactor systems simultaneously. In embodiments, the distributed control architecture allows reactor systems 24a – 24n to operate independently from each other, allowing the engineer to check/repair each reactor system individually. As such, distributed
5 control architecture give the plasma generating system 20 greater flexibility, scalability and maintainability.

[0031] In embodiments, the PLC 22 sends a simple command, such as, turn on (or turn off) the reactor system via the cable 26. Then, the reactor controller 174 takes proper steps to ignite the plasma and report back to the PLC 22 that the operation was successful (or not). Also, the
10 reactor controller 174 continuously monitors the health of plasma once ignition has occurred and, optionally, reports the health condition to the PLC 22 at a preset time interval. In embodiments, the PLC 22 is a standalone device having the capability to support a graphic user interface (GUI) for interface with a human operator. In alternative embodiments, the PLC 22 is included in a computer/server 102 that has a GUI 103 for human interface.

[0032] As depicted in FIG. 4, the reactor system 24a includes a tuner 39 that corresponds to the impedance matching network 38 in FIG. 3 and reduces the amount of microwave energy retrogressing toward the magnetron 34. It is noted that the impedance matching network 38 may include other suitable components, such as isolator (not shown in FIG. 4) for dissipating retrogressing microwaves that travel toward the magnetron 34.

[0033] FIG. 5 shows a cross sectional view of a plasma chamber 42 in FIG. 4, taken along the line 5-5 (i.e. cut along a plane parallel to the paper), according to embodiments of the present disclosure. As depicted, the plasma chamber 42 includes: an inner wall(s) 140; a plasma stabilizer 138; a forward flow inlet 142 connected to the gas line 124 and configured to introduce the forward flow into the plasma chamber; and a reverse flow inlet (which is referred to as
25 “adaptor”) 144 connected to the gas line 128 and configured to introduce the reverse flow into the plasma chamber. Here, the term plasma cavity refers to the enclosed space that is surrounded by the inner wall 140, waveguide 36, forward flow inlet 142 and adaptor 144, where the reverse flow gas and forward flows are processed/reformed in the plasma cavity by the microwave energy transmitted via the waveguide 36.

[0034] In embodiments, the inner wall **140** is formed of a material that is transparent to the microwave energy, such as quartz or ceramic. In embodiments, the inner wall **140** is formed of any other suitable dielectric material that is desirable for uniform flow, thermal resistance, chemical resistance, and electromagnetic transparency. In embodiments, the inner wall **140** has preferably, but not limited to, a shape of hollow circular cylinder.

[0035] FIG. 6 shows a perspective view of the forward flow inlet **142** according to embodiments of the present disclosure. FIG. 7 shows a cross sectional view of the forward flow inlet **142**, taken along the line 7-7, according to embodiments of the present disclosure. As depicted, the forward flow inlet **142** has a hole/adaptor **147** for coupling to the gas line **124** and one or more gas passageways **148** that are formed in the wall thereof. In embodiments, the exits of the gas passageways **148** are located inside the plasma stabilizer **138** so that the plasma stabilizer **138** forms an inner vortex flow **143** using the flow exiting the gas passageways **148**. In embodiments, the inner diameter of the plasma stabilizer **138** may be varied to adjust the outer diameter of the inner vortex flow **143**. In embodiments, as discussed above, the plasma stabilizer **138** may have a shape of hollow circular cylinder and disposed concentrically to the forward flow inlet **142**.

[0036] In embodiments, each gas passageway **148** is arranged to impart spiral motion to the forward flow as the forward flow enters the plasma cavity via the gas passageway **148**. In embodiments, each gas passageway **148** may be curved to enhance the vorticity of the forward flow. In embodiments, the forward flow inlet **142** is formed of any suitable material, such as dielectric material or metal.

[0037] In embodiments, the plasma stabilizer **138** is formed of material that is transparent to the microwave energy, and preferably formed of the same material as the inner wall **140**. In embodiments, the plasma stabilizer **138** is attached to the waveguide **36**, protruding into the plasma cavity, where the axial direction of the plasma stabilizer **138** is parallel to the y-axis. In embodiments, as discussed above, the inner wall **140** may have a shape of a hollow circular cylinder and the plasma stabilizer **138** may be installed concentrically to the inner wall **140**. In embodiments, the forward flow inside the plasma stabilizer **38** forms the inner vortex flow **143** and proceeds toward the other end of the waveguide **36**, more specifically toward the gas outlet

132. FIG. 10 shows a perspective view of the inner vortex flow **143** according to embodiments of the present disclosure. As depicted, the forward flow (or equivalently, inner vortex flow) travels the length of the inner wall **140** in a helical motion until the inner vortex flow exits the gas outlet **132**.

5 **[0038]** In embodiments, upon ignition of a plasma plume (or shortly, plasma) **146** by a plasma igniter (not shown in FIG. 5), the plasma **146** is sustained by the microwave energy transmitted by the microwave generator **34**. In embodiments, the plasma **146** is located within the inner vortex flow **143** so that the gas particles of the inner vortex flow **143** pass through the plasma **146**. In embodiments, the plasma stabilizer **138** determines the outer diameter of the inner
10 vortex flow **143**, preventing the forward flow from bypassing the plasma **146** before exiting the plasma cavity through the gas outlet **132**. In embodiments, the plasma stabilizer **138** aids in keeping the plasma **146** stable by separating the inner vortex flow **143** from the outer vortex flow **145**.

[0039] FIG. 8 shows a perspective view of the adaptor **144** according to embodiments of the
15 present disclosure. FIG. 9 shows a cross sectional view of the adaptor **144**, taken along the line **9-9**, according to embodiments of the present disclosure. As depicted, the adaptor **144** has a hole/adaptor **152** for coupling to the gas line **128**, a hole to form the gas outlet **132**, and one or more gas passageways **151** that are formed in the wall thereof. In embodiments, each gas passageway **151** is arranged to impart spiral motion to the reverse flow as the reverse flow enters
20 the plasma cavity via the gas passageway **151**. In embodiments, each gas passageway **151** may be curved to enhance the vorticity of the reverse flow. In embodiments, the adaptor **144** is formed of preferably, but not limited to Ni alloy, such as Inconel or Hastelloy.

[0040] In embodiments, the reverse flow exiting the adaptor **144** travels toward to the inner wall **140** and then proceeds upwardly (y-axis direction) toward the other end of the waveguide
25 **36** along the inner wall **140** in a helical motion. Subsequently, the reverse flow reverses the flow direction to proceed downwardly and form an outer vortex flow **145**. In embodiments, the rotational axis of the outer vortex flow **145** is substantially parallel to the y-axis. FIG. 11 shows a perspective view of the outer vortex flow **145** according to embodiments of the present disclosure. As depicted, the outer vortex flow **145** has a hollow cylinder shape and has two flow

regions: inner downward flow region **145-1** and an outer upward flow region **145-2**. In embodiments, the inner vortex flow **143** is disposed in the middle hollow portion of the outer vortex flow **145** and surrounded by inner downward flow region **145-1**. It is noted that the gas from the forward flow inlet **142** is mixed with the flow from the adaptor **144** to form the inner vortex flow **143**.

[0041] In embodiments, the outer vortex flow **145** surrounds the inner vortex flow **143**, to thereby shield the inner wall **140** from the plasma **146**. In embodiments, the reverse flow exiting the adaptor **144** may have the ambient temperature and take heat energy from the inner wall **140** as the outer vortex flow **145** travels upwardly along the inner wall **140** in the helical motion.

[0042] In embodiments, the plasma **146** is used to reform the inlet gas to the desired product gas, where the inlet gas is introduced into the plasma cavity by the forward flow inlet **142** and adaptor **144**. In embodiments, the gas composition of the inner vortex flow exiting the forward flow inlet **142** includes CO₂, CH₄ and O₂, and the gas exiting the gas outlet **132** includes CO and H₂ as well as a non-reacted portion of forward flow gas. In embodiments, the preferred distribution for the forward flow is 5%-95% by mass of the total flow into the plasma chamber **42**. In embodiments, the reverse flow may have the same gas composition of the forward flow. In alternative embodiments, the forward flow may have different gas composition from the reverse flow. Also, the gas composition of the forward flow (and/or reverse flow) may be changed during operation. For instance, the forward flow may include a slug of argon to aid ignition of the plasma **146**. In embodiments, the reactor controller **174** adjusts the gas compositions and flow rates of the forward and reverse flows to enhance the plasma stability and efficiency of the chemical reaction in the plasma chamber **42**.

[0043] As discussed above, the reactor controller **174** is coupled to various electrical and/or mechanical control devices/mechanisms in the reactor system **24a**. In embodiments, the reactor controller **174** may form a feedback control system. For instance, the sensor (e.g. **190a**) may be a pressure sensor that measures the pressure inside the plasma chamber **42**, where the signal from the pressure sensor **190a** is processed by the DIO/AIO module **178** and sent to the μ -processor **176**. If the μ -processor **176** determines that the pressure is too low (or too high), the μ -processor **176** sends a control signal to the gas servo valve **190d** (and/or **190e**) through the DIO/AIO

module **178** to adjust the flow rate in the gas line **128**, forming a feedback control mechanism for controlling the pressure inside the plasma chamber **42**.

[0044] It is noted that the plasma chamber **42** in FIG. 4 may have different components and arrangement of the components. For instance, the plasma chamber may not include the forward flow inlet **142**. In another example, the plasma stabilizer **138** may be mounted on the reverse flow inlet **144**. The description of various embodiments of the plasma chamber **42** can be found in a copending U.S. Patent Application Ser. No. 16/752,689, entitled "Plasma reactor for processing gas," filed on January 26, 2020, which is hereby incorporated by reference in its entirety.

[0045] It shall be noted that the computer **102** may be implemented in any instruction-execution/computing device or system capable of processing data, including, without limitation phones, laptop computers, desktop computers, and servers. The present disclosure may also be implemented into other computing devices and systems. Furthermore, aspects of the computer **102** may be implemented in a wide variety of ways including software (including firmware), hardware, or combinations thereof. For example, the functions to practice various aspects of the computer **102** may be performed by components that are implemented in a wide variety of ways including discrete logic components, one or more application specific integrated circuits (ASICs), and/or program-controlled processors. It shall be noted that the manner in which these items are implemented is not critical to the present disclosure.

[0046] It is noted that the reactor controller **174** may include other suitable electrical component that are necessary for operating the μ -processor **176** and the DIO/AIO module **178**. For instance, the memory **180** may be in the form of random-access memory (RAM), read-only memory (ROM) and/or EEPROM. Similarly, the computer/server **102** may include other suitable electrical components that are necessary for operating the PLC **22** and the GUI **103**. For instance, the computer/server **102** may include: a central processing unit (CPU); various input device(s), such as a keyboard, mouse, or stylus; a scanner; one or more storage devices, such as magnetic tape or disk, or an optical medium; a printer controller for communicating with a printer; one or more communication devices that enables connection to remote devices through any of a variety of networks including the Internet, an Ethernet cloud, an FCoE/DCB cloud, a

local area network (LAN), a wide area network (WAN), a storage area network (SAN) or through any suitable electromagnetic carrier signals including infrared signals.

[0047] It will be appreciated to those skilled in the art that the preceding examples and embodiment are exemplary and not limiting to the scope of the present disclosure. It is intended
5 that all permutations, enhancements, equivalents, combinations, and improvements thereto that are apparent to those skilled in the art upon a reading of the specification and a study of the drawings are included within the true spirit and scope of the present disclosure.

What is claimed is:

1. A plasma generating system, comprising:
a microwave generator for generating microwave energy; and
a power supply for providing electrical power to the microwave generator and including a
5 controller that comprises:
at least one microprocessor; and
a module communicatively coupled to the at least one processor and including at
least one of digital input-output (DIO) and analogue input-output (AIO).
- 10 2. A plasma generating system as recited in claim 1, further comprising:
a programmable logic controller (PLC) communicatively coupled to the power supply by
a daisy chain network.
3. A plasma generating system as recited in claim 2, wherein the daisy chain network
15 includes an Ethernet cable.
4. A plasma generating system as recited in claim 2, further comprising:
a graphic user interface (GUI) communicatively coupled to the PLC.
- 20 5. A plasma generating system as recited in claim 1, further comprising:
one or more sensors communicatively coupled to and configured to exchange data with
the module.
6. A plasma generating system as recited in claim 5, wherein the one or more sensors are
25 coupled to the module by a cable harness.
7. A plasma generating system as recited in claim 1, further comprising:
a waveguide coupled to the microwave generator and configured to transmit the
microwave energy therethrough;
30 an inner wall disposed within the waveguide to define a plasma cavity, a plasma being

generated within the plasma cavity using the microwave energy;

an adaptor mounted on a first side of the waveguide and configured to introduce a first gas into the plasma cavity and including a gas outlet through which a gas processed by the plasma exits the plasma cavity; and

5 a first flow rate sensor coupled to the module and configured to measure a flow rate of the first gas.

8. A plasma generating system as recited in claim 7, further comprising;

a valve coupled to the module and configured to control the flow rate of the first gas.

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9. A plasma generating system as recited in claim 7, further comprising;

a flow inlet mounted on a second side of the waveguide and configured to introduce a second gas into the plasma cavity; and

15 a second flow rate sensor coupled to the module and configured to measure a flow rate of the second gas.

10. A plasma generating system as recited in claim 8, further comprising;

a valve coupled to the module and configured to control the flow rate of the second gas.

20 11. A plasma generating system, comprising:

a programmable logic controller (PLC); and

a plurality of reactor systems coupled to the PLC by a daisy chain network, each of the plurality of reactor systems including:

a microwave generator for generating microwave energy; and

25 a power supply for providing electrical power to the microwave generator and including a controller that comprises:

at least one microprocessor; and

a module communicatively coupled to the at least one processor and including at least one of digital input-output (DIO) and analogue input-output (AIO).

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12. A plasma generating system as recited in claim 11, wherein the daisy chain network includes an Ethernet cable.

5 13. A plasma generating system as recited in claim 11, further comprising:
a graphic user interface (GUI) communicatively coupled to the PLC.

14. A plasma generating system as recited in claim 11, wherein each of the plurality of reactor systems further includes:
10 one or more sensors communicatively coupled to and configured to exchange data with the module.

15 15. A plasma generating system as recited in claim 14, wherein the one or more sensors are coupled to the module by a cable harness.

16. A plasma generating system as recited in claim 11, wherein each of the plurality of reactor systems further includes:

a waveguide coupled to the microwave generator and configured to transmit the microwave energy therethrough;
20 an inner wall disposed within the waveguide to define a plasma cavity, a plasma being generated within the plasma cavity using the microwave energy;
an adaptor mounted on a first side of the waveguide and configured to introduce a first gas into the plasma cavity and including a gas outlet through which a gas processed by the plasma exits the plasma cavity; and
25 a first flow rate sensor coupled to the module and configured to measure a flow rate of the first gas.

17. A plasma generating system as recited in claim 16, further comprising;
a valve coupled to the module and configured to control the flow rate of the first gas.

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18. A plasma generating system as recited in claim 16, further comprising;
a flow inlet mounted on a second side of the waveguide and configured to introduce a
second gas into the plasma cavity; and
a second flow rate sensor coupled to the module and configured to measure a flow rate of
5 the second gas.

19. A plasma generating system as recited in claim 18, further comprising;
a valve coupled to the module and configured to control the flow rate of the second gas.

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