[0007] In some embodiments, instead of a sensor that is coupled to an input of an impedance matching network, a processor is used to determine actual delivered power at the input. A voltage and current probe measures a complex voltage and current at an output of a radio frequency (RF) generator. The complex voltage and current is used to calculate theoretical delivered power at the output of the RF generator. The actual delivered power at the input of the impedance matching network is determined as a function of the theoretical delivered power, a cable power attenuation fraction of an RF cable that connects the impedance matching network to the RF generator, and an RF power reflection ratio. The RF power reflection ratio is determined by the processor based on forward power that is measured at the output of the RF generator and reverse power that is measured at the output of the RF generator.

[0008] In various embodiments, a method for modeling cable loss is described. The method includes receiving a measurement of reverse power at a radio frequency (RF) generator, which is coupled via an RF cable to an impedance matching network. The impedance matching network is coupled via an RF transmission line to a plasma chamber. The RF generator has a frequency of operation. The method further includes receiving a measurement of forward power at the RF generator, computing theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power, and calculating a ratio of the reverse power to the forward power to generate an RF power reflection ratio. The method further includes identifying a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator, and calculating a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical power. The method includes calculating actual power to be delivered to the impedance matching network based on the theoretical power and the cable power loss and sending the calculated actual power to the RF generator to generate an RF signal. The method is executed by a processor.

[0009] In several embodiments, a method for using modeled power loss, includes receiving a measurement of reverse power at an RF generator, which is coupled via an RF cable to an impedance matching network. The impedance matching network coupled via an RF transmission line to a plasma chamber. The RF generator has a frequency of operation. The method further includes receiving a measurement of forward power at the RF generator, computing theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power, and calculating a ratio of the ~~of the~~ reverse power to the forward power to generate an

RF power reflection ratio. The method includes identifying a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator and calculating a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical delivered power. The method includes calculating actual power to be delivered to the impedance matching network based on the theoretical delivered power and the cable power loss, and determining an actual power at a node associated with a computer-generated model based on the actual power delivered to the impedance matching network. The method is executed by a processor.

[0010] In some embodiments, a plasma system for using modeled power loss, includes a radio frequency (RF) generator for supplying forward power. The RF generator has a frequency of operation. The plasma system further includes an impedance matching circuit coupled to the RF generator for receiving the forward power and to generate a modified RF signal based on the forward power. The plasma system includes an RF cable coupling the RF generator to the impedance matching circuit to facilitate a transfer of the forward power to the impedance matching circuit, and a plasma chamber coupled to the impedance matching circuit via an RF transmission line. The plasma chamber is used for generating plasma based on the modified RF signal. The plasma system includes a sensor coupled to the RF generator to measure the forward power and to measure reverse power. The reverse power is reflected from the plasma towards the RF generator via the RF cable. The plasma system further includes a host system coupled to the sensor for receiving the measurement of the forward power and the reverse power. The host system is configured to compute theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power, calculate a ratio of the of the reverse power to the forward power to generate an RF power reflection ratio, and identify a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator. The host system is further configured to calculate a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical delivered power. The host system is configured to calculate actual power to be delivered to the impedance matching circuit network based on the theoretical delivered power and the cable power loss and send the calculated actual power to the RF generator to control the RF generator.

[0011] Some advantages of the above-described embodiments include using a cable power attenuation fraction of an RF cable, an RF power reflection ratio of an output of an RF generator, and theoretical delivered power at the output of the RF generator to

[0065] Figure 2A is a diagram of an embodiment of a cable model 180, which is a computer-generated model of an RF cable, e.g., the RF cable 104A, or 104B, or 104C (Figure 1), etc. The cable model 180 is generated by the processor 110 (Figure 1) to represent a cable power loss of an RF cable. For example, the cable model 180 represents the cable power loss $P_{delloss}$, which is a loss of delivered power that is attributed by the processor 110 to the RF cable 104A. Power that is delivered at an output 184 of the cable model 180 is a function of a power delivered at an input 182 of the cable model 180 and a cable power loss attributed to an RF cable that is represented by the cable model 180. For example, power P_{delout} that is delivered at an output 184 of the cable model 180 is a difference between the power delivered P_{delin} at an input 182 of the cable model 180 and the cable power loss $P_{delloss}$ that is attributed to the RF cable 104A.

[0066] A cable power loss of an RF cable is a function of cable power attenuation fraction of the RF cable and a RF power reflection ratio associated with the RF cable, e.g., the RF cable 104A, or 104B, or 104C (Figure 1), etc. For example, the cable power loss $P_{delloss}$ attributed by the processor 110 to the RF cable 104A is dependent upon the cable power attenuation fraction A of the RF cable 104A and the RF power reflection ratio Γ^2 of the RF cable 104A.

[0067] Figure 2B is a diagram of an embodiment of another cable model 182, which is a computer-generated model of an RF cable. The cable model 182 is an example of the cable model 180 (Figure 2A). Cable power loss that is attributed by the processor 110 to an RF cable is a function of power delivered to an input 188 of the cable model 186, cable power attenuation fraction of the RF cable, and RF power reflection ratio associated with the RF cable. For example, the cable power loss $P_{delloss}$ is provided by equation (2) above. Power delivered at an output 190 of the cable model ~~190~~ is a function of the power delivered at the input 188 and the cable power loss associated with the cable model 186. For example, the power ~~delivered~~ P_{delout} delivered at the output 190 is calculated as a difference between the power ~~delivered~~ P_{delin} delivered at the input 188 and the cable power loss $P_{delloss}$ of the RF cable 104A.

[0068] It should be noted that the input 188 is an example of the input 182 (Figure 2A) and the output 190 is ~~a function~~ an example of the output 184 (Figure 2A).

[0069] Figure 3 is a diagram used to illustrate that a cable power attenuation fraction associated with attenuation of power by an RF cable is dependent upon a length of the RF cable and a frequency of operation of an RF generator that is connected to the RF

cable. For example, the processor 110 (Figure 1) determines the cable power attenuation fraction A of the RF cable 104A (Figure 1) based on a length L of the RF cable 104A and a frequency of operation of the x MHz RF generator that is connected to the RF cable 104A and that supplies an RF signal via the RF cable 104A to the impedance matching network 102 (Figure 1).

[0070] Figure 4 is an embodiment of a graph ~~190~~ 191 that is shown to illustrate a relationship between a cable power attenuation fraction of an RF cable and a frequency of an RF generator that is connected to the RF cable to provide an RF signal via the RF cable and the impedance matching network 102 (Figure 1) to the plasma chamber 112 (Figure 1). The graph ~~190~~ 191 includes a plot of a cable power attenuation fraction, measured in decibels per 100 feet, of an RF cable, versus a square root of a frequency of operation of an RF generator that is coupled to the RF cable. The cable power attenuation fraction is plotted on a y-axis and the square root of frequency of operation is plotted on an x-axis.

[0071] The graph ~~190~~ 191 includes a plot 192 of an RF cable 1 and a plot 194 of another RF cable 2. The plot 194 is linear and the plot 192 is a plot of a polynomial. In some embodiments, the plot 192 is an exponential function.

[0072] It should be noted that a cable power attenuation fraction of an RF cable increases with a frequency of operation of an RF generator that is coupled to the RF cable.

[0073] In some embodiments, instead of every 100 feet of an RF cable, a cable power attenuation fraction is measured every 10 feet or 1 feet or 2 feet or any other number of feet of the RF cable. In various embodiments, instead of feet, any other unit of length, e.g., meters, or centimeters, or inches, etc., is used.

[0074] In various embodiments, a cable power attenuation fraction of an RF cable that is coupled to an RF generator is extrapolated to a frequency of operation of the RF generator by the processor 110 based on high frequencies, e.g., frequencies above 100 MHz, frequencies above 90 MHz, frequencies above 60 MHz etc., and based on cable power attenuations fractions corresponding to the frequencies.

[0075] Figure 5 shows embodiments of graphs 196 and 198 to illustrate a relationship between an error between a value of a variable, e.g., voltage, current, etc., that is generated using a modeled value of the variable without use of the equation (2) and a measured value of the variable. For example, the graph 196 plots a percentage error in a modeled voltage that is generated at an input of a computer-generated model of an impedance

matching network versus a voltage that is measured at the input. Also, in this example, the percentage error is plotted on a y-axis and the measured voltage in plotted on an x-axis. In this example, the measured voltage is sensed using a voltage sensor at an output of an RF cable that is represented by a computer-generated model and that is coupled to the impedance matching network. Further, in this example, the modeled voltage is generated by propagating a value of a voltage at an input of the computer-generated model of the RF cable via the computer-generated model of the RF cable. To illustrate, a modeled voltage is propagated by ~~generated~~ generating a directional sum of the voltage and of modeled voltages of one or more elements of the computer-generated model of the RF cable. In this illustration, the elements include capacitors, or inductors, or a combination thereof. The elements of the computer-generated model of the RF cable have the same or similar characteristics as that of components of an RF cable that is represented by the computer-generated model. For example, when the RF cable has a capacitance of M and an inductance of N, the elements have a capacitance of M and an inductance of N. As another example, when the components include a real capacitor coupled in series with a real inductor, the elements include a modeled capacitor in series with a modeled inductor. As yet another example, when the components include a real capacitor coupled in parallel with a real inductor, the elements include a modeled capacitor in parallel with a modeled inductor. It should be noted examples of the elements of a computer-generated model include one or more capacitors, one or more inductors, or a combination thereof.

[0076] Similarly, the graph 198 plots a percentage error in a modeled current that is generated at an input of a computer-generated model of an impedance matching network versus a current that is measured at the input. The percentage error in current is plotted on a y-axis and the measured current in plotted on an x-axis.

[0077] As shown in graphs 196 and 198, percentage errors are close to and above one percent.

[0078] In some embodiments, an input of a computer-generated model of an impedance matching network is coupled to an output of a computer-generated model of an RF cable that is connected to the impedance matching network.

[0079] Figure 6 shows embodiments of graphs 202 and 204 to illustrate a reduction in error in a variable when equation (2) is used to determine a cable power loss. The graph 202 plots a percentage error in a modeled voltage that is determined based on a

102, and the capacitors and/or inductors and/or resistors are connected with each other in the same manner, e.g., serial, parallel, etc. as that within the impedance matching network 102. To provide an illustration, when the impedance matching network 102 includes a capacitor coupled in series with an inductor, the impedance matching model 150 also includes the capacitor coupled in series with the inductor.

[0086] As another example, the impedance matching network 102 includes one or more electrical circuit components and the impedance matching model 150 includes a design, e.g., a computer-generated model, of the impedance matching network 102. The computer-generated model may be generated by the processor 110 based upon input signals received from a user via an input hardware unit. The input signals include signals regarding which electrical circuit components, e.g., capacitors, inductors, resistors, etc., to include in a model and a manner, e.g., series, parallel, etc., of coupling the electrical circuit components with each other. As another example, the impedance matching network 102 includes hardware electrical circuit components and hardware connections between the electrical circuit components and the impedance matching model 150 includes software representations of the hardware electrical circuit components and of the hardware connections. As yet another example, the impedance matching model ~~152~~ 150 is designed using a software program and the impedance matching network 102 is made on a printed circuit board.

[0087] As used herein, in some embodiments, electrical circuit components include resistors, capacitors, inductors, connections between the resistors, connections between the inductors, connections between the capacitors, and/or connections between a combination of the resistors, inductors, and capacitors. Examples of connections between resistors, inductors, and/or capacitors include one or more conductors.

[0088] Similarly, the RF transmission model 152 and the RF transmission line 114 have similar characteristics. For example, the RF transmission model 152 has the same number of capacitors and/or inductors as that within the RF transmission line 114, and the capacitors and/or inductors are connected with each other in the same manner, e.g., serial, parallel, etc. as that within the RF transmission line 114. To further illustrate, when the RF transmission line 114 includes a capacitor coupled in parallel with an inductor, the RF transmission model 152 also includes the capacitor coupled in parallel with the inductor. As yet another example, the RF transmission line 114 includes one or more electrical circuit components and the RF transmission model 152 includes a design, e.g., a computer-generated model, of the RF transmission line 114.

[0094] Moreover, in various embodiments, the actual delivered power at the model node O2 is propagated via a portion of the chuck model 154 to generate actual delivered power at an intermediate model node within the chuck model 154. The intermediate model node of the chuck model 154 is between electrical circuit components of the chuck model 154 at one side of the intermediate model node and electrical circuit components of the chuck model 154 at another side of the intermediate model node.

[0095] In some embodiments, the actual power $P_{delactual}$, the actual power at the model node O1, the actual power at the model node O2, and/or the actual power at the model node O3 is sent by the processor 110 to one or more of the x, y, and z MHz RF generators to control RF signals that are generated by the one or more of the x, y, and z MHz RF generators to control plasma within the plasma chamber 112. For example, the processor 110 identifies that the actual power $P_{delactual}$ exceeds a threshold. The processor 110 sends a signal to the DSP 160 of the x MHz RF generator to change power of an RF signal supplied by the RF supply 162. The RF signal with the changed amount of power is sent via the RF cable 104A (Figure 1), the impedance matching network 102, and the RF transmission line 114 (Figure 1) to the chuck 164 to modify properties of plasma within the plasma chamber 112 to achieve the threshold.

[0096] In some embodiments, any functions described herein as performed by the processor 110 are performed by a processor of an RF generator or by a combination of the processor 110 and the processor of the RF generator.

[0097] Figure 8 is a diagram of an embodiment of the host system 118. The host system 118 includes the processor 110, a memory device 122, an input device 220, an output device 222, an input/output (I/O) interface 270, an I/O interface 272, a network interface controller (NIC) 274, and a bus 275. The processor 110, the ~~storage~~ memory device ~~278~~122, the input device ~~266~~220, the output device ~~268~~222, the I/O interface 270, the I/O interface 272, and the NIC 274 are coupled with each other via the bus 275. Examples of the input device 220 include a mouse, a keyboard, a stylus, etc. Examples of the output device 222 include a display, a speaker, or a combination thereof. The display may be a liquid crystal display, a light emitting diode display, a cathode ray tube, a plasma display, etc. Examples of the NIC 274 include a network interface card, a network adapter, etc.

[0098] Examples of an I/O interface include an interface that provides compatibility between pieces of hardware coupled to the interface. For example, the I/O

CLAIMS

1. A method for modeling cable loss, comprising:

receiving a measurement of reverse power at a radio frequency (RF) generator, the RF generator coupled via an RF cable to an impedance matching network, the impedance matching network coupled via an RF transmission line to a plasma chamber, the RF generator having a frequency of operation;

receiving a measurement of forward power at the RF generator;

computing theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power;

calculating a ratio of the reverse power to the forward power to generate an RF power reflection ratio;

identifying a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator;

calculating a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical power;

calculating actual power to be delivered to the impedance matching network based on the theoretical power and the cable power loss; and

sending the calculated actual power to the RF generator to generate an RF signal,

wherein the method is executed by a processor.

2. The method of claim 1, wherein the measurements of the forward and reverse powers are received from a complex voltage and current sensor, the complex voltage and current sensor coupled to an output of the RF generator to measure the reverse power at the RF generator and to measure the forward power at the RF generator.

3. The method of claim 1, wherein the reverse power includes reflected power, wherein the reflected power includes power reflected towards the RF generator from the plasma chamber.

4. The method of claim 1, wherein the RF generator includes an RF power supply and a digital signal processor (DSP) coupled to the RF power supply, the DSP used for providing a value of power of the RF signal to the RF power supply.

5. The method of claim 1, wherein the impedance matching network is used for matching an impedance of a load with that of a source, the load coupled to the impedance matching network at one end of the impedance matching network and the source coupled to the impedance matching network at another end of the impedance matching network.

6. The method of claim 1, wherein the RF transmission line includes an RF rod that is coupled to an RF strap and includes an additional RF rod, the additional RF rod coupled to the RF strap at one end of the additional RF rod and coupled to a chuck of the plasma chamber at another end of the additional RF rod.

7. The method of claim 1, wherein the plasma chamber includes a chuck and an upper electrode, the upper electrode facing the chuck.

8. The method of claim 1, wherein the forward power includes power supplied by the RF generator.

9. The method of claim 1, further comprising identifying the frequency of operation from a list of frequencies, wherein identifying the cable power attenuation fraction comprises determining the cable power attenuation fraction as corresponding to the frequency of operation.

10. The method of claim 1, wherein calculating the cable power loss as the function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical delivered power comprises:

calculating a sum of one and the RF power reflection ratio to generate a first result;

calculating a difference between one and the RF power reflection ratio to generate a second result ~~to generate a third result~~;

computing a ratio of the first result to the second result to generate a third result;

computing a product of the theoretical delivered power, the cable power attenuation fraction, and the third result to generate the cable power loss.

11. The method of claim 1, wherein calculating the actual power to be delivered to the impedance matching network based on the theoretical delivered power and the cable power

loss comprises calculating the actual power as a difference between the theoretical delivered power and the cable power loss.

12. The method of claim 1, wherein the RF signal has power that is generated based on the calculated actual power.

13. A method for using modeled power loss, comprising:

receiving a measurement of reverse power at a radio frequency (RF) generator, the RF generator coupled via an RF cable to an impedance matching network, the matching network coupled via an RF transmission line to a plasma chamber, the RF generator having a frequency of operation;

receiving a measurement of forward power at the RF generator;

computing theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power;

calculating a ratio of the of the reverse power to the forward power to generate an RF power reflection ratio;

identifying a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator;

calculating a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical delivered power;

calculating actual power to be delivered to the impedance matching network based on the theoretical delivered power and the cable power loss; and

determining an actual power at a node associated with a computer-generated model based on the actual power delivered to the impedance matching network,

wherein the method is executed by a processor.

14. The method of claim 13, wherein the measurements of the forward and reverse powers are received from a complex voltage and current sensor, the complex voltage and current sensor coupled to an output of the RF generator to measure the reverse power at the RF generator and to measure the forward power at the RF generator.

15. The method of claim 13, wherein determining the actual power at the node based on the actual power delivered to the impedance matching network comprises propagating the

actual power delivered to the impedance matching network via the computer-generated model to calculate a value of the actual power at the node.

16. The method of claim 15, wherein propagating the actual power delivered to the impedance matching network comprises calculating a directional sum of the actual power delivered to the impedance matching network and one or more power values associated with one or more electrical circuit components of the computer-generated model.

17. The method of claim 13, wherein the node includes an input node at an input of the computer-generated model, or an output node at an output of the computer-generated model, or an intermediate node within the computer- generated model.

18. The method of claim 13, further comprising:

sending the actual power at the node to the RF generator to control the RF generator, wherein sending the actual power at the node to the RF generator to control the RF generator comprises sending a value of the actual power at the node for generating an RF signal to achieve a threshold.

19. A plasma system for using modeled power loss, comprising:

a radio frequency (RF) generator for supplying forward power, the RF generator having a frequency of operation;

an impedance matching circuit coupled to the RF generator for receiving the forward power and to generate a modified RF signal based on the forward power;

an RF cable coupling the RF generator to the impedance matching circuit to facilitate a transfer of the forward power to the impedance matching circuit;

a plasma chamber coupled to the impedance matching circuit via an RF transmission line, the plasma chamber for generating plasma based on the modified RF signal;

a sensor coupled to the RF generator to measure the forward power and to measure reverse power, the reverse power reflected from the plasma towards the RF generator via the RF cable;

a host system coupled to the sensor for receiving the measurement of the forward power and the reverse power,

wherein the host system is configured to:

compute theoretical power delivered to the impedance matching network as a difference between the forward power and the reverse power;

calculate a ratio of the of the reverse power to the forward power to generate an RF power reflection ratio;

identify a cable power attenuation fraction of the RF cable based on the frequency of operation of the RF generator;

calculate a cable power loss as a function of the RF power reflection ratio, the cable power attenuation fraction, and the theoretical delivered power;

calculate actual power to be delivered to the impedance matching circuit network based on the theoretical delivered power and the cable power loss; and

send the calculated actual power to the RF generator to control the RF generator.

20. The plasma system of claim 19, wherein the impedance matching circuit lacks a connection to a sensor used to measure forward power at the impedance matching circuit and reverse power reflected at the impedance matching circuit.