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(54) **ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER**

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(57) **ABSTRACT**

A system and method for electrically charging a combustion flame with a power supply.

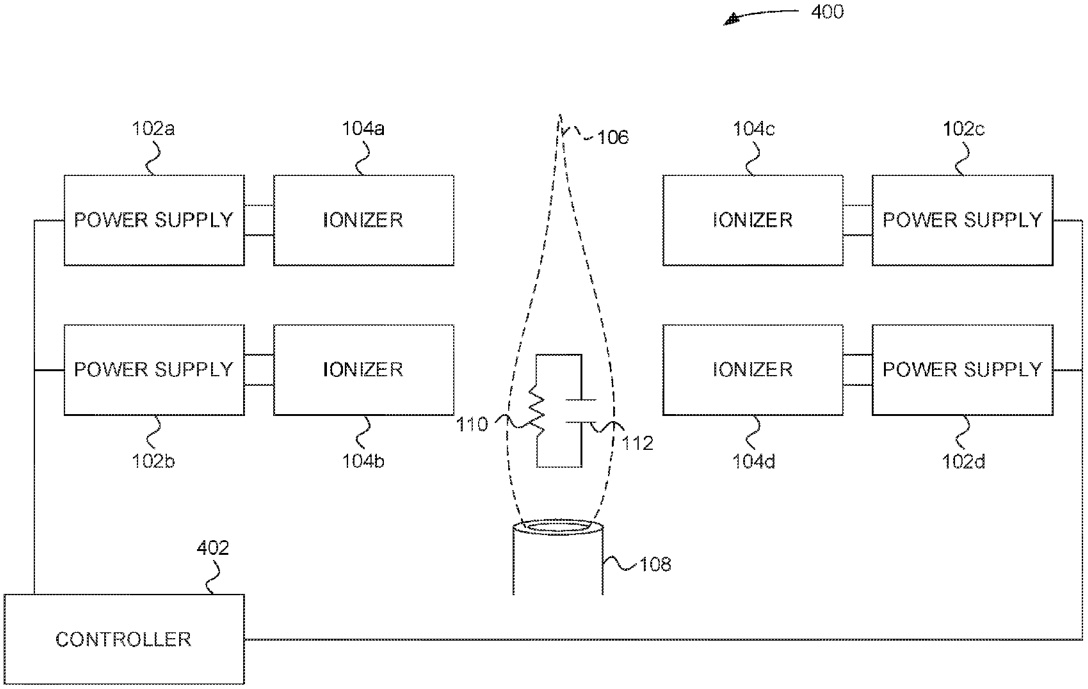


FIG. 1

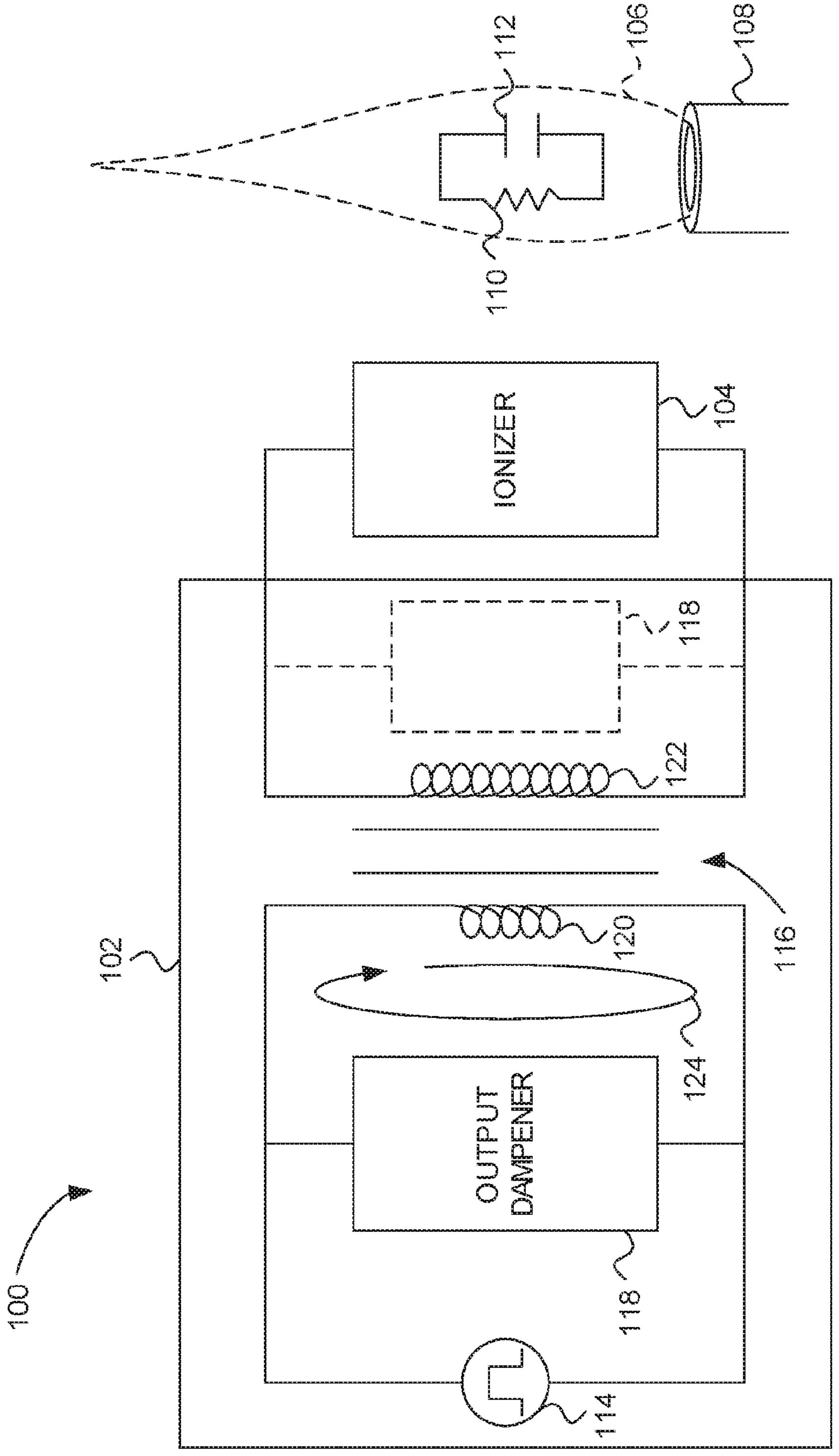

100
102
104
IONIZER
106
108
110
112
116
118
122
120
124
OUTPUT DAMPENER
118
114

FIG. 2

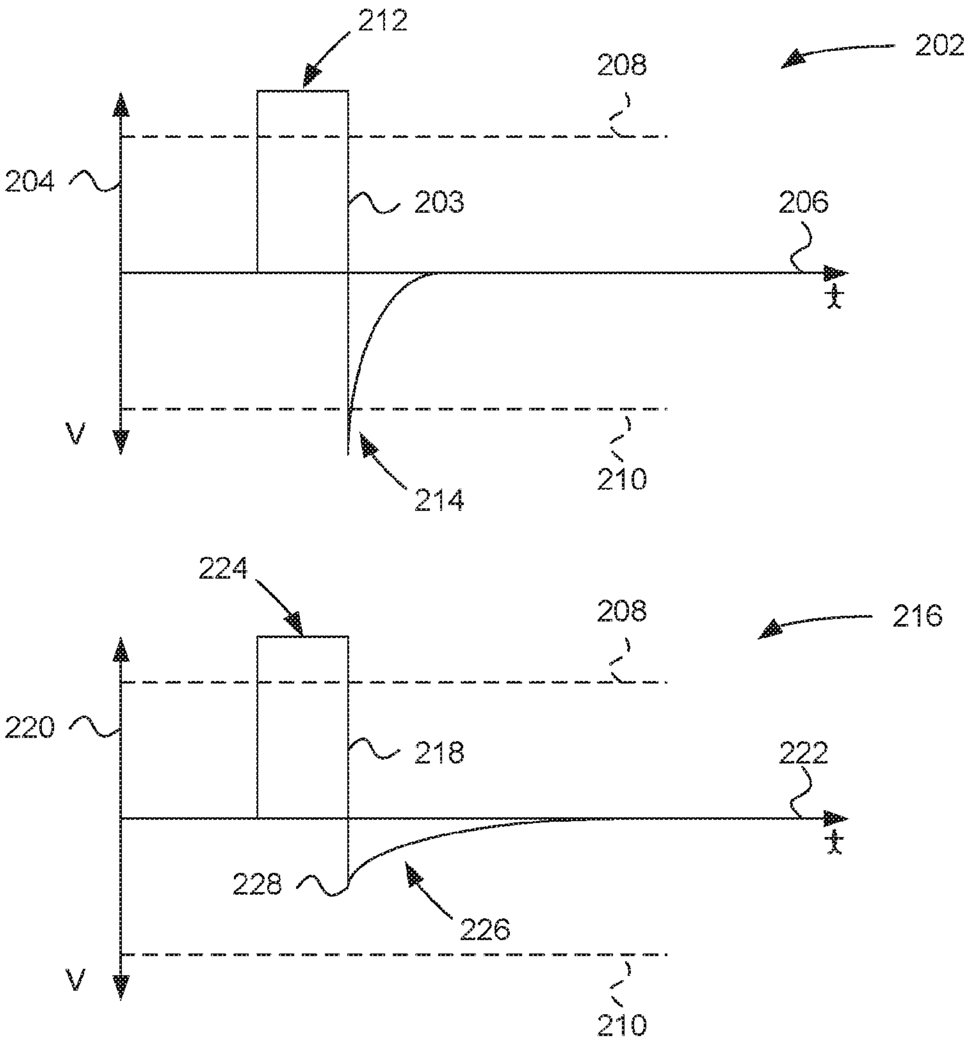

212
202
208
204
203
206
t
V
210
214
224
208
216
220
218
222
t
228
226
V
210

FIG. 3

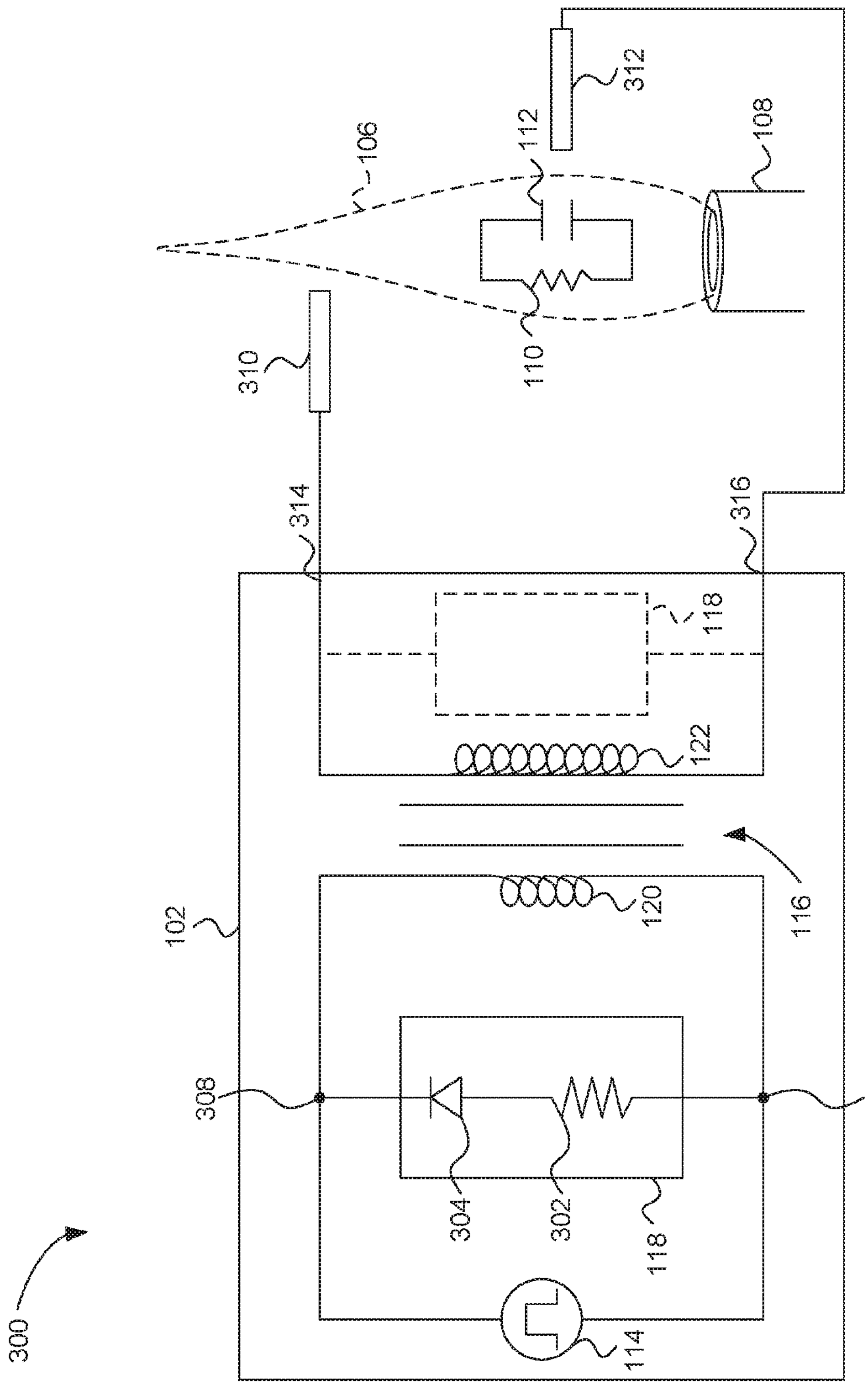

300
102
308
304
302
118
306
114
120
116
122
118
314
316
310
110
112
106
312
108

FIG. 4

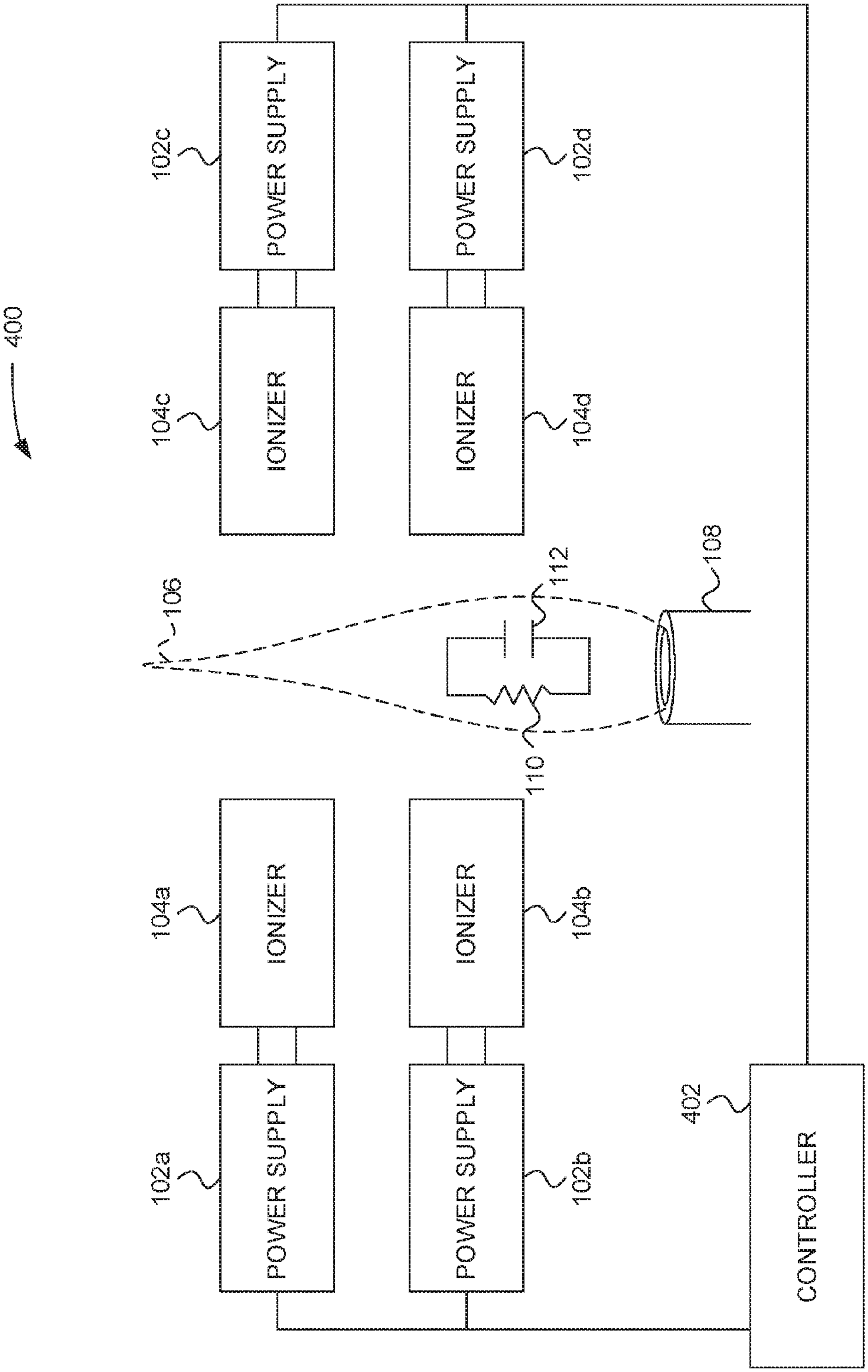
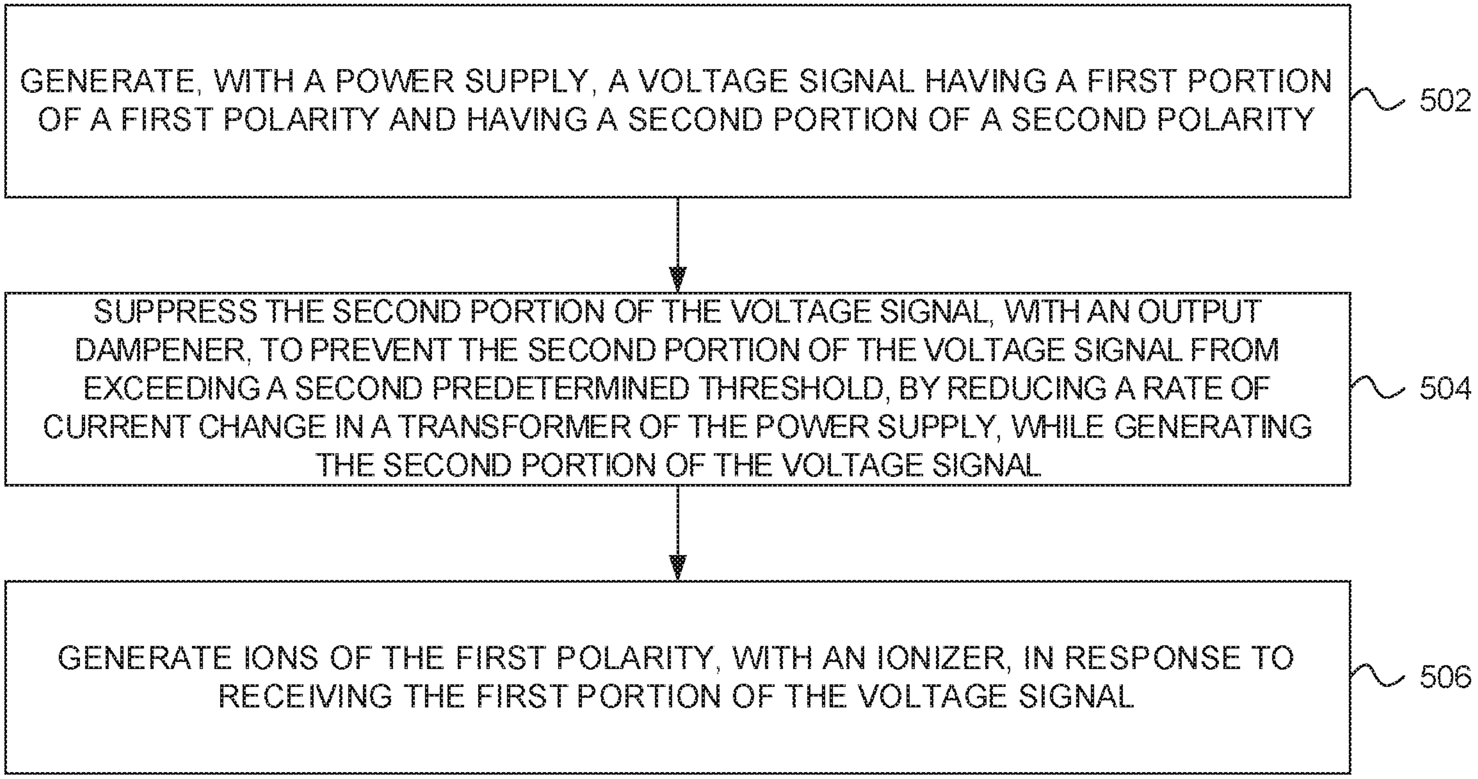

400
102c
POWER SUPPLY
104c
IONIZER
102d
POWER SUPPLY
104d
IONIZER
106
112
108
110
104a
IONIZER
104b
IONIZER
102a
POWER SUPPLY
102b
POWER SUPPLY
402
CONTROLLER

FIG. 5



GENERATE, WITH A POWER SUPPLY, A VOLTAGE SIGNAL HAVING A FIRST PORTION OF A FIRST POLARITY AND HAVING A SECOND PORTION OF A SECOND POLARITY

SUPPRESS THE SECOND PORTION OF THE VOLTAGE SIGNAL, WITH AN OUTPUT DAMPENER, TO PREVENT THE SECOND PORTION OF THE VOLTAGE SIGNAL FROM EXCEEDING A SECOND PREDETERMINED THRESHOLD, BY REDUCING A RATE OF CURRENT CHANGE IN A TRANSFORMER OF THE POWER SUPPLY, WHILE GENERATING THE SECOND PORTION OF THE VOLTAGE SIGNAL

GENERATE IONS OF THE FIRST POLARITY, WITH AN IONIZER, IN RESPONSE TO RECEIVING THE FIRST PORTION OF THE VOLTAGE SIGNAL

ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a U.S. Continuation Application which claims priority benefit under 35 U.S.C. §120 (pre-AIA) of co-pending International Patent Application No. PCT/US2015/040277, entitled "ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER," filed Jul. 14, 2015 (docket number 2651-220-04); which application claims priority benefit from U.S. Provisional Patent Application No. 62/030,960, entitled "ASYMMETRICAL UNIPOLAR FLAME IONIZER USING A STEP-UP TRANSFORMER," filed Jul. 30, 2014 (docket number 2651-220-02); each of which, to the extent not inconsistent with the disclosure herein, is incorporated herein by reference.

SUMMARY

[0002] According to an embodiment, a system for electrically controlling a combustion flame may include a burner configured to generate the combustion flame. The combustion flame includes a resistance and a capacitance. The system may include an ionizer positioned proximate to the burner to supply ions of a first polarity to the combustion flame to charge the capacitance of the combustion flame to one or more voltage levels. The system may include a power supply coupled to the ionizer and configured to provide an output voltage signal of the first polarity to the ionizer to excite the ionizer to supply the ions of the first polarity to the combustion flame. The power supply may include a transformer and an output dampener operatively coupled in parallel to the transformer. The output dampener can suppress a second polarity of the output voltage signal to limit delivery of ions of the second polarity to the combustion flame by the ionizer.

[0003] According to an embodiment, a system for electrically controlling a combustion flame may include a first power supply configured to generate a first output voltage pulse of a first polarity in excess of a first predetermined threshold. The first power supply may include a first step-up transformer. The first power supply may include a first output dampener coupled to the first step-up transformer and configured to at least partially suppress a second output voltage pulse of a second polarity to prevent the second output voltage pulse from exceeding a second predetermined threshold. The system may include a second power supply configured to generate a third output voltage pulse of the first polarity in excess of the first predetermined threshold. The second power supply may include a second step-up transformer. The second power supply may include a second output dampener coupled to the second step-up transformer and configured to at least partially suppress a fourth output voltage pulse of the second polarity to prevent the fourth output voltage pulse from exceeding the second predetermined threshold. The second polarity may be different than the first polarity. The system may include a first ionizer operatively coupled to the first power supply and configured to supply first ions of the first polarity to a combustion flame to charge the combustion flame, in response to receipt of the first output voltage pulse. The system may include a second ionizer operatively coupled to the second power supply and configured to supply second ions of the first polarity to the combustion flame to charge the combustion flame, in response to receipt of the third output voltage pulse. The system may include a controller communicatively coupled to the first power supply and to the second power supply to selectively cause the first ionizer and the second ionizer to supply the first ions and the second ions to the combustion flame.

[0004] According to an embodiment, a method for electrically controlling a combustion flame may include generating, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity. The first portion of the voltage signal is greater than or equal to a first predetermined threshold. The method may include suppressing the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while generating the second portion of the voltage signal. The method may include generating ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal. Generating ions can include supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or more characteristics of the combustion flame.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

[0006] FIG. **2** is a graphical illustration of a voltage suppression function of the system for applying voltage to a combustion flame, according to an embodiment.

[0007] FIG. **3** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

[0008] FIG. **4** is a block diagram of a system for applying voltage to a combustion flame, according to an embodiment.

[0009] FIG. **5** is a flow diagram of a method for electrically controlling a combustion flame, according to an embodiment.

DETAILED DESCRIPTION

[0010] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the disclosure.

[0011] Electrodynamic combustion control may be used to control and/or vary characteristics of a combustion flame or combustion reaction. The application of a voltage, charge, current, and/or electric field to a combustion flame may be used to improve heat distribution of the flame, to stabilize the flame, and/or to prevent flame impingement. The application of electrodynamic combustion control may also improve the energy efficiency, shape, and/or heat transfer of the flame.

[0012] The inventors have identified several issues that may be associated with applying a high-power voltage to a combustion flame. For example, if an electrode of a power supply is directly coupled or inserted within a combustion flame, and the combustion flame inadvertently contacts a grounded conductor or a grounded housing, the combustion flame can electrically couple the power supply to grounded contact point and potentially damage the power supply.

[0013] Another example of an issue identified by the inventors is that traditional power supply configurations may be limited to charging a load with the voltage that is only as high as the power supply can generate. Accordingly, a power supply configuration that could charge a load to a voltage that is higher than the capacity of the power supply may enable the power supply to be designed or built to lower voltage specifications than the desired load voltage.

[0014] Disclosed herein are methods and systems of applying a unipolar charge to a combustion flame. The methods and systems enable physical isolation between the power supply and the combustion flame while enabling the power supply to charge the combustion reaction to higher voltages than the power supply itself can output.

[0015] FIG. **1** illustrates an electrodynamic flame control system **100** for charging a combustion flame to one or more voltage levels, according to one embodiment. As used herein "electrodynamic flame control" may refer to the application of a voltage, charge, current, and/or electric field to control combustion flame behavior and to improve heat distribution in a combustion volume. In one embodiment, the application of the charge or current to the combustion flame includes supplying ions or electrons to the combustion flame with an ionizer. The electrodynamic flame control system **100** includes a power supply **102** and an ionizer **104** for charging a combustion flame **106** to one or more voltage levels, according to one embodiment.

[0016] The power supply **102** may be configured to charge the combustion flame **106** to one or more voltage levels without physically contacting, connecting to, or coupling with the combustion flame **106**, according to one embodiment. Physically decoupling the power supply **102** from the combustion flame **106** can protect the power supply **102** from inadvertent damage, e.g., short-circuiting through the combustion flame **106** to ground. The power supply **102** may be electrically coupled to the ionizer **104** to charge the combustion flame **106** to one or more voltage levels. In one embodiment, the ionizer **104** is disposed or positioned proximate to, but external to, the combustion flame **106** so that a physical connection or coupling is absent between the power supply **102** and the combustion flame **106**. The power supply **102** can be configured to supply the ionizer **104** with a high-power voltage, e.g., greater than or equal to approximately 4 kilovolts ("kV"), to enable the ionizer **104** to ionize fluids that are proximate to or adjacent to the ionizer **104** and/or that are proximate to the combustion flame **106**. According to one embodiment, the power supply **102** can be configured to supply the ionizer **104** with a high-power voltage that is less than or equal to a breakdown voltage, e.g., +/−10 kV, of the fluid that is to be ionized. The corona onset voltage can be +/−4 kV for some fluids. In one embodiment, the power supply **102** can be configured to supply the ionizer **104** with a high-power voltage that is greater than or equal to the corona onset voltage of a fluid and that is less than or equal to a breakdown voltage for the fluid. By supplying ions to the combustion flame **106**, rather than directly charging the combustion flame **106** with a voltage, the power supply **102** can selectively charge the combustion flame **106** to one or more voltage levels without physically contacting, connecting to, or coupling with the combustion flame **106**.

[0017] The ionizer **104** can be implemented using any one of a number of ionizer configurations to supply ions to the combustion flame **106** in order to charge the combustion flame **106** to one or more voltage levels, according to one embodiment. For example, the ionizer **104** can include one or more electrodes, one or more fluid displacement mechanisms, one or more fluid supply mechanisms, and/or one or more fluid delivery mechanisms, according to various embodiments. For example, the one or more electrodes can include a single emitter electrode, an emitter electrode and a collector electrode, or multiple emitter electrodes and multiple collector electrodes. Other names for the electrodes can include corona electrode, counter electrode, target electrode cathode, anode, or the like. In one embodiment, the ionizer **104** includes a single emitter electrode and uses the combustion flame **106** or a burner **108** as a collector electrode. When the voltage between the emitter electrode and collector electrode of the ionizer **104** approaches, equals, and/or exceeds the corona onset voltage, e.g., 4 kV, the carrier fluid molecules that are proximate to or in the vicinity of the emitter electrode begin ionizing. The ionizer **104** can be configured to provide a strong ionic stream, i.e., an ionic current, from just a few kilovolts of voltage. The ions can have a charge that is of the same polarity as the emitter electrode, and the ions are repulsed from the emitter electrode in the direction of the combustion flame **106** and/or in the direction of the collector electrode. Because the combustion flame **106** includes a resistance **110** (e.g., 3-4 megaohms) and a capacitance **112** (e.g., 3-5 picofarads "pF"), receipt of cations or anions (i.e., positive or negative charged ions) by the combustion flame **106** results in an increase in voltage or electrical potential in the combustion flame **106**.

[0018] The voltage of the combustion flame **106** that results from injection of ions can be characterized, described, or defined in terms of charge, capacitance, and/or current. The voltage across the capacitance **112** of the combustion flame **106** can be expressed in terms of charge, capacitance, and/or current as:

$$V=Q/C \qquad \text{(Equation 1);}$$

and

$$V=(I*t)/C \qquad \text{(Equation 2),}$$

[0019] where V is voltage,

[0020] Q is charge,

[0021] C is capacitance,

[0022] I is current, and

[0023] t is time.

Equation 1simply states that the voltage is proportional to the charge Q stored by a capacitance C, so increasing charge on a fixed capacitance will proportionally increase the voltage across a capacitance. Similarly, Equation 2 expresses charge as a product of current and time and shows that providing current, such as a stream of ions, to a fixed capacitance for a period of time will also increase the voltage across the capacitance. Accordingly, by configuring the power supply **102** and the ionizer **104** to supply the combustion flame **106** with ions, i.e., charge, the power supply **102** and the ionizer **104** can selectively charge the combustion flame **106** to one or more voltage levels, according to various embodiments.

[0024] The power supply **102** may be configured to excite the ionizer **104** to generate unipolar ions, according to one embodiment. If the power supply **102** provides or excites the ionizer **104** with a voltage that is equal to or in excess of a positive corona onset voltage, the ionizer **104** generates positive ions. However, if the power supply **102** provides the ionizer **104** with a voltage that is equal to or less than a negative corona onset voltage, the ionizer **104** generates negative ions. Therefore, if the power supply **102** causes the ionizer **104** to supply the combustion flame **106** with positive ions, but then causes the ionizer **104** to supply the combustion flame **106** with negative ions, the power supply **102** may inadvertently, unintentionally, and/or undesirably discharge the combustion flame **106**. The power supply **102** is configured to provide the ionizer **104** with one or more voltage signals that enable the ionizer **104** to generate unipolar ions, i.e., ions of a single polarity, according to one embodiment.

[0025] The power supply **102** includes a voltage supply **114**, a transformer **116**, and an output dampener **118**, according to one embodiment. The voltage supply **114** selectively generates square-wave pulses of half a square-wave period, one square-wave period, or multiple square-wave periods, according to various embodiments. In one embodiment, the voltage supply **114** is implemented as a DC voltage supply in series with a switch that is operative to selectively decouple the DC voltage supply from the transformer **116** and/or from the output dampener **118**, according to various embodiments.

[0026] The transformer **116** can be coupled between the voltage supply **114** and the ionizer **104** to convert a first voltage signal having a first voltage level into a second voltage signal having a second, higher, voltage level, according to one embodiment. The transformer **116** may be a step-up transformer that converts a voltage signal that is, for example, between 100-500 V into a voltage signal that is, for example, between 4-10 kV, according to one embodiment. The transformer **116** may include a primary winding **120** and a secondary winding **122**. The primary winding **120** may have a number of turns that is less than a number of turns of the secondary winding **122**. The primary winding **120** may be connected to the voltage supply **114**, and the secondary winding **122** may be connected to the ionizer **104**, according to one embodiment.

[0027] The output dampener **118** enables the power supply **102** to provide a first polarity output voltage signal that exceeds or surpasses a first polarity corona onset voltage while limiting, suppressing, dampening, and/or preventing a second polarity output voltage signal from exceeding or surpassing a second polarity corona onset voltage, according to one embodiment. For example, the output dampener **118** enables the power supply **102** to provide a first polarity output voltage signal that is above a first polarity corona onset voltage of 4 kV while prohibiting the power supply **102** from generating a second polarity output voltage signal that is below or more negative than −4 kV. In other embodiments, the output dampener **118** enables the power supply **102** to provide a first polarity voltage signal that is below or more negative than −4 kV while prohibiting the power supply **102** from generating a second polarity voltage signal that is above or more positive than 4 kV. Thus, the power supply **102** can be configured to generate a positive high-power voltage that is equal to or greater than a positive corona onset voltage, or the power supply **102** can be configured to generate a negative high-power voltage that is equal to or more negative than a negative corona onset voltage, according to various embodiments.

[0028] The output dampener **118** can include one or more passive electronic components configured to suppress or dampen power supply output voltage surges or spikes of a particular polarity, according to one embodiment. The output dampener **118** can be referenced by several different terms, such as output voltage controller, output voltage suppressor, output voltage filter, output filter, voltage filter, output limiter, output voltage limiter, field regulator, magnetic field regulator, magnetic field rate suppressor, or the like. In one implementation, the output dampener **118** is a resistor operatively or electrically coupled in parallel to the voltage supply **114** and to the transformer **116**. In another implementation, the output dampener **118** is a resistor in series with a diode, with the resistor and diode being coupled in parallel to the voltage supply **114** and to the transformer **116**. The output dampener **118** can be operatively or electrically coupled to the primary winding **120** of the transformer **116** or can be optionally and alternatively coupled to the secondary winding **122** of the transformer **116**, according to various embodiments.

[0029] In one embodiment, the operation of the output dampener **118** can be described in terms of magnetic flux ϕ. After the voltage supply **114** applies a voltage to the primary winding **120**, current begins flowing through the primary winding **120**. As the current through the primary winding **120** increases with time, the magnetic flux ϕ that permeates the primary winding **120** and the secondary winding **122** also increases with time. The change in magnetic flux ϕ with respect to time determines the magnitude of the voltage generated across the secondary winding **122**. Faraday's law describes the magnitude of the voltage across the secondary winding **122** as follows:

$$V=N^*(d\phi/dt) \qquad \text{(Equation 3)},$$

where V is the voltage across the secondary winding **122**,

[0030] N is the number of turns of the secondary winding **122**, and

[0031] Dϕ/dt is the rate of change of the magnetic flux ϕ through the secondary

winding **122** with respect to time.

[0032] Since the voltage across the secondary winding **122** is proportional to the change in the magnetic flux ϕ, the increases in rate of the magnetic flux ϕ generate a positive voltage and decreases in the rate of the magnetic flux ϕ generate a negative voltage, across the secondary winding **122**. Furthermore, faster magnetic flux ϕ changes, i.e., higher rates of change, generate higher voltages across the secondary winding **122**. Therefore, the output dampener **118** can enable the power supply **102** to generate a positive voltage that exceeds a positive corona onset voltage by not impeding increases in the magnetic flux ϕ, and the output dampener **118** can limit, suppress, or dampen the negative voltage generated by the power supply **102** by slowing the rate by which the magnetic flux ϕ collapses or decreases when the voltage supply **114** removes voltage from the primary winding **120**, according to one embodiment. In another embodiment, the output dampener **118** is configured to enable the power supply **102** to generate a negative voltage that exceeds or is more negative than the negative corona onset voltage while limiting, suppressing, dampening, or preventing the power supply output voltage from exceeding the positive corona onset voltage.

[0033] The rate by which the magnetic flux ϕ decreases is proportional to the rate by which current through the primary winding **120** decreases. The output dampener **118** can reduce the maximum negative voltage across the secondary winding **122** by reducing the rate of change of the magnetic flux ϕ by reducing the rate of change of the current through the primary winding **120**, according to one embodiment. Without the output dampener **118**, when the power supply **102** removes voltage from across the primary winding **120**, e.g., by opening a switch, the power supply **102** removes a path for current in the primary winding **120** to continue flowing. The current that was flowing through the primary winding **120** is abruptly changed from a first current level to a second current level that is approximately 0 amps ("A"). The abrupt change from the first current level to the second current level results in a rapid decrease in the magnetic flux ϕ and therefore can result in a large induced negative voltage across the secondary winding **122**.

[0034] The output dampener **118** provides a current path **124** to allow current that was flowing through the primary winding **120** to at least partially continue flowing. In one embodiment, the output dampener **118** includes a resistor in series with a diode, and the diode is oriented to allow current to flow in the direction of the current path **124**. The current that was flowing through the primary winding **120** gradually decreases as it dissipates through the resistance of the output dampener **118**, but the initial rate of change of the current through the primary winding **120** from a first current level to a second current level can be significantly reduced, as compared to when the power supply **102** does not include the output dampener **118**. As a result, the output dampener **118** enables the power supply **102** to excite the ionizer **104** to selectively generate ions of a single polarity for charging the combustion flame **106** to one or more voltage levels, according to one embodiment.

[0035] While the discussion above is generally directed towards embodiments where the output dampener **118** is connected in parallel to the primary winding **120**, it is to be understood that in other implementations of the power supply **102**, the output dampener **118** can perform the same function by being connected to the secondary winding **122**, instead of to the primary winding **120**.

[0036] FIG. **2** illustrates graphs of the operation of the power supply **102** (shown in FIG. **1**) with and without the implementation of the output dampener **118** (shown in FIG. **1**), according to one embodiment. A graph **202** illustrates an example of an output voltage signal **203** that could be generated by the power supply **102**, if the power supply **102** does not include the output dampener **118**. The graph **202** includes an x-axis **204** that represents output voltage levels with respect to a y-axis **206** that represents time. The graph **202** also includes an indication of a first corona onset voltage **208** and an indication of a second corona onset voltage **210**. In one embodiment, the first corona onset voltage **208** is a positive corona onset voltage, and the second corona onset voltage **210** is a negative corona onset voltage. In one embodiment, the first corona onset voltage **208** is approximately 4 kV, and the second corona onset voltage **210** is approximately −4 kV. The output voltage signal **203** includes a first section **212** and a second section **214**. The first section **212** is generated when the voltage supply **114** (shown in FIG. **1**) applies a first input voltage level to the transformer **116** (shown in FIG. **1**). As shown, the first section **212** exceeds the first corona onset voltage **208** to cause the ionizer **104** (shown in FIG. **1**) to generate positively charged ions. The second section **214** is generated when the voltage supply **114** removes the first input voltage level from the transformer **116**, or when the voltage supply **114** rapidly applies a second input voltage level to the transformer **116** that is lower than the first voltage level. The second section **214** exceeds the second corona onset voltage **210** and causes the ionizer **104** to generate negatively charged ions, resulting in the discharge of the combustion flame **106**.

[0037] A graph **216** illustrates an example of an output voltage signal **218** that could be generated by the power supply **102**, if the power supply **102** includes or implements the output dampener **118**, according to one embodiment. The graph **216** includes an x-axis **220** that represents output voltage levels with respect to a y-axis **222** that represents time. The graph **216** includes an indication of the first corona onset voltage **208** and an indication of the second corona onset voltage **210**. The output voltage signal **218** includes a first section **224** and a second section **226**. The first section **224** is generated when the voltage supply **114** applies a first input voltage level to the transformer **116**. As shown, the first section **224** exceeds the first corona onset voltage **208** to cause the ionizer **104** to generate positively charged ions. The second section **226** is generated when the voltage supply **114** applies a second input voltage level to the transformer **116**, e.g., when the voltage supply **114** removes the first input voltage level from the transformer **116**. As shown, by incorporating the output dampener **118** into the power supply **102**, the maximum negative amplitude **228** of the second section **226** of the output voltage signal **218** can be limited, suppressed, or dampened so that the second section **226** does not exceed the second corona onset voltage **210**. In other words, implementation of the output dampener **118** prevents the power supply **102** from causing the ionizer **104** to generate negatively charged ions, according to one implementation of the output dampener **118**. In other implementations, the output dampener **118** can be used to enable the ionizer **104** to generate negatively charged ions while preventing the ionizer **104** from generating positively charged ions.

[0038] FIG. **3** illustrates an electrodynamic flame control system **300** for charging the combustion flame **106** to one or more voltage levels, according to one embodiment. The electrodynamic flame control system **300** represents one particular implementation of the electrodynamic flame control system **100** of FIG. **1**, according to one embodiment. In the electrodynamic flame control system **300**, the output dampener **118** includes a resistor **302** electrically connected or coupled to a diode **304** to enable current to flow from a first node **306** to a second node **308**. The resistor **302** and the diode **304** reduces the negative rate of current change through the primary winding **120** when the voltage supply **114** removes voltage from the primary winding **120**. By reducing the negative rate of current change through the primary winding **120**, the output dampener **118** reduces the negative rate of magnetic flux ϕ change and therefore reduces the peak value of the voltage that is induced across the secondary winding **122** when the voltage supply **114** removes voltage from across the primary winding **120**, according to one embodiment. In other implementations of the output dampener **118**, the orientation of the diode **304**

can be changed to allow current to flow from the second node **308** to the first node **306**. Such a reversal in orientation could be used to apply a negative polarity voltage to the transformer **116** while limiting the peak value of a positive voltage induced across the secondary winding **122** when the voltage supply **114** removes the negative polarity voltage from across the primary winding **120**, according to one embodiment.

[0039] In one embodiment, the ionizer **104** of the electrodynamic flame control system **100** can be implemented in the electrodynamic flame control system **300** as a first electrode **310** and a second electrode **312**. The first electrode **310** can be electrically coupled or connected to a first output terminal **314** and the second electrode **312** can be electrically coupled or connected to a second output terminal **316**. The electrodes **310**, **312** receive voltage, energy, and/or power from the power supply **102**, to supply ions to the combustion flame **106** to charge the combustion flame **106** to one or more voltage levels. In one embodiment, the first electrode **310** is a conductor such as a wire, a piece of metal, and/or a needle. In one embodiment, second electrode **312** is a conductor that is larger, e.g., has more surface area and/or more volume, than the first electrode **310**. In one embodiment, the first electrode **310** is positioned proximate to and external to the combustion flame **106**. In one embodiment, proximate to and external to the combustion flame **106** include being positioned at least 1 inch away from the combustion flame **106**. In one embodiment, the second electrode **312** is positioned proximate to and external to the combustion flame **106**. In one embodiment, the first electrode **310** is positioned on one side of the combustion flame **106** and the second electrode **312** is positioned on another side of the combustion flame **106**. In alternative implementations, the second electrode **312** is positioned within the combustion flame **106**. In one embodiment, the second output terminal **316** of the power supply **102** is electrically coupled or connected to the burner **108** so that the burner **108** functions as the second electrode **312**. In one embodiment, the second electrode **312** is omitted from the electrodynamic flame control system **300** and the first electrode **310** is used to supply ions to the combustion flame **106**.

[0040] The power supply **102** may be configured to charge the combustion flame **106** to a particular voltage that may be higher than an output voltage of the power supply **102**, according to one embodiment. The combustion flame **106** includes the capacitance **112**, which may be charged by the receipt of ions from the electrodes **310**, **312**. As described previously in Equation 1 and Equation 2, the voltage across the capacitance **112** can be expressed in terms of charge, e.g., $V=Q/C$, or in terms of current, e.g., $V=(l*t)/C$. The power supply **102** may be configured to provide an output voltage to the ionizer **104** (shown in FIG. **1**) or to the electrodes **310**, **312** that is between 4-10 kV because 4 kV can be the corona onset voltage and because 10 kV can be the breakdown voltage of the surrounding or proximate fluid. Assuming, the capacitance **112** is approximately 3 pF, the power supply **102** and the electrodes **310**, **312** can charge the combustion flame **106** to 15 kV by supplying 45 nanocoulombs ("nC") to the capacitance **112**. Described in another way, the power supply **102** and electrodes **310**, **312** can charge the combustion flame **106** to 15 kV by supplying 45 nanoampere-seconds ("nA-s"), which can be supplied with an ion current of 4.5 milliamperes ("mA") for 10 microseconds ("µs"). Alternatively, the power supply **102** and the electrodes **310**, **312** can charge the combustion flame **106** to 40 kV by supplying 120 nA-s with 12 mA for 10 µs (i.e., 100 kHz pulse). Thus, by using the ionizer **104** or the electrodes **310**, **312**, the power supply **102** can be configured to charge the combustion flame **106** to a voltage that is higher than the output voltage of the power supply **102**, according to various embodiments.

[0041] FIG. **4** illustrates an electrodynamic flame control system **400** for charging the combustion flame **106** to one or more voltage levels, according to one embodiment. The electrodynamic flame control system **400** includes a controller **402** that is communicatively coupled or operatively coupled to control multiple instances of the power supply **102** (inclusive of power supplies **102***a*, **102***b*, **102***c*, **102***d*), according to one embodiment. The controller **402** can be configured to selectively operate the voltage supplies **114** (shown in FIG. **1**) of the power supplies **102** and the corresponding ionizers **104** (inclusive of ionizer **104***a*, **104***b*, **104***c*, **104***d*). The controller **402** can be configured to customize the quantity, duration, and polarity of ions supply to the combustion flame **106**. In one embodiment, the controller **402** causes the power supplies **102***a*, **102***b*, **102***c*, **102***d* to sequentially provide ions of a single polarity to the combustion flame **106** by time-multiplexing the ion generation. In another embodiment, the controller **402** causes one or more of the power supplies **102***a*, **102***b*, **102***c*, **102***d* to generate positive ions to selectively charge the combustion flame **106** while causing others of the power supplies **102***a*, **102***b*, **102***c*, **102***d* to selectively and sequentially generate negative ions to selectively discharge the combustion flame **106**. In one implementation, the controller **402** time-multiplexes the operation of the power supplies **102***a*, **102***b*, **102***c*, **102***d* by: causing the power supply **102***a* to selectively charge the combustion flame **106**; causing the power supply **102***b* to selectively discharge the combustion flame **106**; causing the power supply **102***c* to selectively charge the combustion flame **106**; and causing the power supply **102***d* to selectively discharge the combustion flame **106**. More or less power supplies **102** and ionizers **104** can be implemented to customize the quantities, polarity, and duration of ions supply to the combustion flame **106**, according to various embodiments.

[0042] FIG. **5** illustrates a method **500** for operating an electrodynamic combustion system, according to one embodiment.

[0043] At block **502**, the method generates, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity, according to one embodiment. The first portion of the voltage signal can be greater than or equal to a first predetermined threshold.

[0044] At block **504**, the method suppresses the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while generating the second portion of the voltage signal, according to one embodiment.

[0045] At block **506**, the method generates ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal, according to one embodiment. Generating ions can include supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or more characteristics of the combustion flame.

[0046] While various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

What is claimed is:

1. A system for electrically controlling a combustion flame, comprising:

a burner configured to generate the combustion flame,
  wherein the combustion flame includes a resistance and a capacitance;
an ionizer positioned proximate to the burner to supply ions of a first polarity to the combustion flame to charge the capacitance of the combustion flame to one or more voltage levels; and
a power supply coupled to the ionizer and configured to provide an output voltage signal of the first polarity to the ionizer to excite the ionizer to supply the ions of the first polarity to the combustion flame,
  wherein the power supply includes a transformer and an output dampener operatively coupled in parallel to the transformer,
  wherein the output dampener suppresses a second polarity of the output voltage signal to limit delivery of ions of the second polarity to the combustion flame by the ionizer.

2. The system of claim **1**, wherein the capacitance is between three and five picofarads (3-5 pF).

3. The system of claim **1**, wherein the ionizer is positioned at least 1 inch away from combustion flame.

4. The system of claim **1**, wherein the first polarity is positive and the second polarity is negative.

5. The system of claim **1**, wherein the first polarity is negative and the second polarity is positive.

6. The system of claim **1**, wherein the ionizer includes an emitting electrode.

7. The system of claim **6**, wherein the ionizer includes a collecting electrode.

8. The system of claim **7**, wherein the emitting electrode and the collecting electrode are positioned on opposite sides of the combustion flame to direct a flow of the ions into the combustion flame.

9. The system of claim **7**, wherein the collecting electrode is the burner that is configured to generate the combustion flame.

10. The system of claim **1**, wherein the ionizer is configured to supply the ions upon excitation with approximately 4 kV.

11. The system of claim **1**, wherein output voltage signal of the first polarity is a square-wave pulse.

12. The system of claim **1**, wherein the power supply includes a primary winding and a secondary winding.

13. The system of claim **12**, wherein the output dampener is electrically coupled in parallel to the primary winding.

14. The system of claim **12**, wherein the output dampener is electrically coupled in parallel to the secondary winding.

15. The system of claim **12**, wherein the output dampener includes a resistor.

16. The system of claim **15**, wherein the output dampener includes a diode electrically coupled in series to the resistor.

17. The system of claim **16**, wherein the diode is oriented to allow current to continue flowing through the primary winding of the transformer after power is removed from the primary winding.

18. A system for electrically controlling a combustion flame, comprising:

a first power supply configured to generate a first output voltage pulse of a first polarity in excess of a first predetermined threshold,
  wherein the first power supply includes a first step-up transformer,
  wherein the first power supply includes a first output dampener coupled to the first step-up transformer and configured to at least partially suppress a second output voltage pulse of a second polarity to prevent the second output voltage pulse from exceeding a second predetermined threshold;
a second power supply configured to generate a third output voltage pulse of the first polarity in excess of the first predetermined threshold,
  wherein the second power supply includes a second step-up transformer,
  wherein the second power supply includes a second output dampener coupled to the second step-up transformer and configured to at least partially suppress a fourth output voltage pulse of the second polarity to prevent the fourth output voltage pulse from exceeding the second predetermined threshold,
  wherein the second polarity is different than the first polarity;
a first ionizer operatively coupled to the first power supply and configured to supply first ions of the first polarity to a combustion flame to charge the combustion flame, in response to receipt of the first output voltage pulse;
a second ionizer operatively coupled to the second power supply and configured to supply second ions of the first polarity to the combustion flame to charge the combustion flame, in response to receipt of the third output voltage pulse; and
a controller communicatively coupled to the first power supply and to the second power supply to selectively cause the first ionizer and the second ionizer to supply the first ions and the second ions to the combustion flame.

19. The system of claim **18**, wherein the first predetermined threshold is approximately 4 kV and the second predetermined threshold is approximately −4 kV.

20. The system of claim **18**, wherein the first polarity is positive and the second polarity is negative.

21. The system of claim **18**, wherein the controller time-multiplexes operation of the first power supply and the second power supply so that the first output voltage pulse and the third output voltage pulse are generated sequentially.

22. The system of claim **18**, wherein the first output dampener includes a first resistor and a first diode, wherein the first diode is oriented to enable a first current to continue flowing through a primary winding of the first transformer, wherein the second output dampener includes a second resistor and a second diode, wherein the second diode is oriented to enable a second current to continue flowing through a primary winding of the second transformer.

23. The system of claim **18**, wherein the first ionizer includes a first emitter electrode and a first collector electrode, wherein the second ionizer includes a second emitter electrode and a second collector electrode.

24. The system of claim **23**, wherein the first emitter electrode and the first collector electrode are positioned on first opposite sides of the combustion flame, and the second emitter electrode and the second collector electrode are positioned on second opposite sides of the combustion flame.

25. The system of claim **18**, further comprising:

a third power supply configured to generate a fifth output voltage pulse of the second polarity in excess of the second predetermined threshold,

wherein the third power supply includes a third step-up transformer,

wherein the third power supply includes a third output dampener coupled to the third step-up transformer and configured to at least partially suppress a sixth output voltage pulse of the first polarity to prevent the sixth output voltage pulse from exceeding the first predetermined threshold; and

a third ionizer operatively coupled to the third power supply and configured to supply third ions of the second polarity to the combustion flame to charge the combustion flame, in response to receipt of the fifth output voltage pulse,

wherein the controller is configured to time multiplex operation of the third power supply to selectively cause the third power supply to generate the fifth output pulse to supply the combustion flame with the third ions of the second polarity.

26. The system of claim **18**, wherein the combustion flame includes a resistance and a capacitance, wherein the capacitance is approximately 3-5 pF.

27. A method for electrically controlling a combustion flame, comprising:

generating, with a power supply, a voltage signal having a first portion of a first polarity and having a second portion of a second polarity,

wherein the first portion of the voltage signal is greater than or equal to a first predetermined threshold;

suppressing the second portion of the voltage signal, with an output dampener, to prevent the second portion of the voltage signal from exceeding a second predetermined threshold, by reducing a rate of current change in a transformer of the power supply, while generating the second portion of the voltage signal; and

generating ions of the first polarity, with an ionizer, in response to receiving the first portion of the voltage signal,

wherein generating ions includes supplying the ions to a combustion flame to charge the combustion flame to a voltage to alter one or more characteristics of the combustion flame.

28. The method of claim **27**, wherein the combustion flame includes a capacitance.

29. The method of claim **28**, wherein the capacitance is between three and five picofarads (3-5 pF).

30. The method of claim **27**, wherein the first polarity is positive and the second polarity is negative.

31. The method of claim **27**, wherein the first predetermined threshold is 4 kV and the second predetermined threshold is −4 kV.

32. The method of claim **27**, wherein the output dampener includes a resistor and a diode coupled in series, wherein the output dampener is coupled in parallel to the transformer.

33. The method of claim **27**, wherein the transformer includes a primary winding and a secondary winding and the output dampener is coupled to the primary winding.

34. The method of claim **27**, wherein suppressing the second portion of the voltage signal to prevent the second portion of the voltage signal from exceeding the second predetermined threshold prevents the ionizer from generating ions of the second polarity.

35. The method of claim **27**, wherein the first predetermined threshold is a corona onset voltage for a fluid that is proximate to the ionizer.

36. The method of claim **27**, wherein the second predetermined threshold is a negative corona onset voltage.

37. The method of claim **27**, wherein the ionizer includes an emitter electrode and a collector electrode.

38. The method of claim **27**, wherein the ionizer includes an emitter electrode and the combustion flame functions as a collector electrode.

39. The method of claim **27**, wherein the ionizer includes an emitter electrode and a burner is coupled to the power supply to function as a collector electrode, wherein the burner generates the combustion flame.

40. The method of claim **27**, wherein the power supply generates the voltage signal in response to receiving a command signal from a controller.

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