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Transformer-less Grid-Connected High-Voltage Marx Pulse Generator with Unity Power Factor for Domestic Drinking Water Disinfection

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Qatar has no rivers, thus the main natural water resource in Qatar is the groundwater table. The average groundwater recharge from rainfall is approximately 55.9 million m^3/year, in addition to 2.2 million m^3/year inflow of groundwater from Saudi Arabia, i.e. the total average renewable groundwater resource is 58.1 million m^3/year for the period 1972–2005. Desalinated sea water and treated sewage are non-conventional water sources in Qatar. The quantities of produced and treated wastewater in the country were 55 and 53 million m^3 in 2005 respectively. In 2005, a total water withdrawal of 444 million m^3 was estimated, which are divided unequally into agricultural, municipal and industrial purposes. The Permanent Water Resources Committee (PWRC) was established in April 2004 to secure water resources for various uses for the benefit of Qatar. Qatar has carried out a number of studies, and established committees for the unification of integrated water resources management as follows: Increasing natural recharge by drilling wells with a special design. Development of water monitoring and irrigation scheduling. Artificial recharge of groundwater. Development of deep aquifers. Increasing treatment and reuse of waste-water: The amount of treated sewage increased from 46 million m^3 in 2004 to 58 million m^3 in 2006. All of the above mentioned facts clarify the importance of securing water (quality and quantity) for the state of Qatar. Many disease-causing germs may be present in water supplies. Sixty percent of all persons living in developing countries live without an adequate supply of drinking water where unsafe water is a major cause of infant mortality in these countries. Table 1 lists some of the germs that inhabit water and which can be harmful to humans. Table 1: Water inhabiting germs Germs Minimum dose for infection Survival time in water, days Escherichia coli 1,000,000 4–16 Vibrio cholera 3 7–32 Campylobacter jejuni 500 16–49 Salmonella typhi 3 4–35 Hapatitis Type A 1 Unavailable Entamoeba coli 10 10–16 Giardia lamblia 10 16–77 Water disinfection processes kill micro-organisms in the drinking water. Disinfection can be achieved by means of chemical disinfectants such as chlorine, which is the most commonly used chemical for disinfection because of its low price. It also remains in water, which inhibits reproduction and growth of the germs.

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However, this process may produce toxic disinfection byproducts which are very harmful to human health. Other disinfection processes such as ozonization or ultraviolet light are expensive for drinking water disinfection. The objective of this work is to implement an electrical disinfection process for controlling germs in water, since the germ cells are destroyed when the electric field strength and pulse duration are above critical values, i.e. dielectric breakdown of the cell membrane. In electrical disinfection water treatment techniques, the high voltage sources used can be classified into: high voltage DC generators, high voltage AC generators, and high voltage pulse generators. The main disadvantage in case of continuous DC sources is the degradation effect on electrodes (electrolysis of electrodes). Although the electrolysis is less in case of AC sources, the AC field application has a dead band region. Since the application time is of the order of a few milliseconds, some bacteria may pass through the electrodes when the electric field has a low strength. On the other hand, pulsed electric field is an effective solution to guarantee killing all harmful germs and avoid electrolysis of electrodes. In PEF processing, water is passed through a small treatment chamber where it is subjected to a short pulse of very high voltage. The high voltage field created across the liquid kills microorganisms by disrupting cell membranes. By applying a high PEF with of sufficient pulse width, an electrical discharge in water will occur. The electric discharges in water can effectively create a variety of simultaneous aspects such as shock waves, ultraviolet radiation, and the formation of chemically active radicals acting on biological cells and chemical compounds dissolved in water. Generally, there are two main types of PEF treatments, namely, underwater pulsed corona discharge and pulsed arc discharge. In corona discharge, the streamer filaments do not propagate across electrodes gap, while in case of arc discharge, the streamers bridge the electrodes. As a result, the pulsed corona has lower power requirements compared to the pulsed arc discharge. In this work, underwater pulsed corona discharge will be considered. In this work, a new grid-connected high-voltage pulsed power generator is proposed to generate pulsed streamers and plasma inside water, which will react with germs and destroy them.

The proposed generator consists of:

(i) Uncontrolled full-bridge rectifier to rectify the grid voltage,
(ii) DC-DC Boost Converter (BC) in conjunction with Capacitor-diode voltage multipliers (CDVMs) to assure operating with unity input power factor (PFC feature) and elevate the rectified voltage to a proper voltage level,
(iii) Conventional solid-state Marx generator, as the generated voltage from BC and CDVMs stage is used to charge the Marx generator capacitors (which are connected in parallel during the charging process),

then when it is needed to generate a pulse, these capacitors are connected in series to discharge in the load during the pulse duration. The charging and discharging cycles are repeated sequentially to generate train of repetitive pulses. The load here is the water to be purified, which electrically can be represented as a resistive load. The value of this resistance depends on the conductivity of water, i.e. depends on the amount of dissolved salts in the water. The generated high voltage pulse is applied across high voltage electrodes, and the water sample to be treated should exist between these two electrodes. The generated pulsed electric field has the ability to kill germs in the water, since by applying the pulsed electric field, an ultraviolet radiation will be produced and will destroy the structure of the germs.

The main advantages of the proposed approach can be summarized as follows:

(i) The proposed generator has no step-up low frequency transformer which reduces the generator weight and volume and enhances the generator efficiency.
(ii) The proposed generator can draw a sinusoidal input current at unity power factor thanks to the existence of PFC feature provided by the BC.
(iii) Relatively low voltage semiconductor devices and capacitors will be employed which affects positively on the cost, i.e. it can be considered as a cost effective high-voltage pulse generator for domestic applications.