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Research Article

Zero Carbon Emission Based on Carbon-free World Power Grid

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ABSTRACT

This paper designs a globally smart energy frame for zero carbon emission covering electricity, transport, industry, etc. all sectors. Primarily, Carbon-free World Power Grid (CFWPG) is proposed here; converter-train as the pivotal technology is proffered, to construct Inertia-endowed Convert-station and DC Transformer for integrating remote generation, DC transmission, AC local grid and DC sub-grid into CFWPG configuration; supportive technologies including Multi-function Energy Storage are listed; the decisive factors of low-priced electricity are given. In order to prove zero carbon emission fully viable, non-carbon transport methods and carbon-free metal productions are particularly discussed as innovative improvement examples of other sectors. In the future, it is expected that more than 95% energy will be gained through CFWPG; production and energy consumption modes will be upgraded; and low-priced electricity will make carbon consumption become a luxury.

Key words: Carbon-free; Converter-train; Convert-station; DC Transmission; Decline of carbon emission; Global power grid; Mitigation of greenhouse gas emission; Multi-level inverter; Smart energy; Smart grid; World power grid; Zero carbon emission

INTRODUCTION

Carbon Emission is a globally urgent issue to be solved. It has been resulting in atmosphere temperature ascending, which has been incurring fierce climate problems, such as extreme chilliness and torridity, more violent hurricane, more frequent flood and drought. Much more sadly, Polar Regions, many ecologic circles, islands, tropical rain forests, and so on are disappearing. Catastrophic bushfires like 4 months burning in Australia and even that absurdly happened in Amazon will be more. All spring from greedy-selfish human consuming too much carbonaceous fossil fuel. And it is disillusionary that the deterioration is still going on. Since 80% of today's global energy continues to be generated by fossil fuels, a shift to low-carbon energy sources will take many decades [1]. World carbon dioxide (CO_2) emission by sector in 2017 is: power 39%; transport 23%; industry 23%; buildings 10%; other 5% [2].

The status will be changed radically. In fact, decline of carbon emission, even getting the zero, can be fulfilled in all sectors. Almost all the problems can be solved by **electricity**.

CARBON-FREE WORLD POWER GRID CONFIGURATION

The suitable power grid configuration based on non-carbon energy is indispensable supposing electricity is the only way out to realize zero carbon emission. So, primarily, Carbon-free World Power Grid (CFWPG) is offered here. The configuration with core components is shown as Figure 1. It can advance zero carbon emission availably.

Usually, instantaneous renewable energy generation capacity is hard to match local peak-valley demand in real time. CFWPG can realize worldwide random energy collection and smart power transmission-supply; that is to say, it can solve the asynchronous supply-demand-peak-valley problem among different time zones. The temporarily surplus power will be stored in OEST or MFES to ensure optimal energy utilization. In a word, via CFWPG, worldwide-distributed carbon-free generation will efficiently provide sufficient power to worldwide-distributed consumers.

In contrast, nowadays AC grid drastically depends on thermal power plants burning carbonaceous fossil. Though renewable energy is desired to be the substitute, it is unstable and discontinuous. Furthermore, AC grid requires synch of all power plants, and is unfit for long distance transmission due to efficiency and stability. DC transmission has no such problems, but cannot provide inertia to enhance resilience of AC grid. Presently, extra-high voltage DC transmission based on SCR can only get the maximum level of 1.3 MV, usually transmits power between point-to-point AC grids with several hundred miles, and accompanies electromagnetic pollution. Today's AC grid and DC transmission are insufficiently high in efficiency and safety. These

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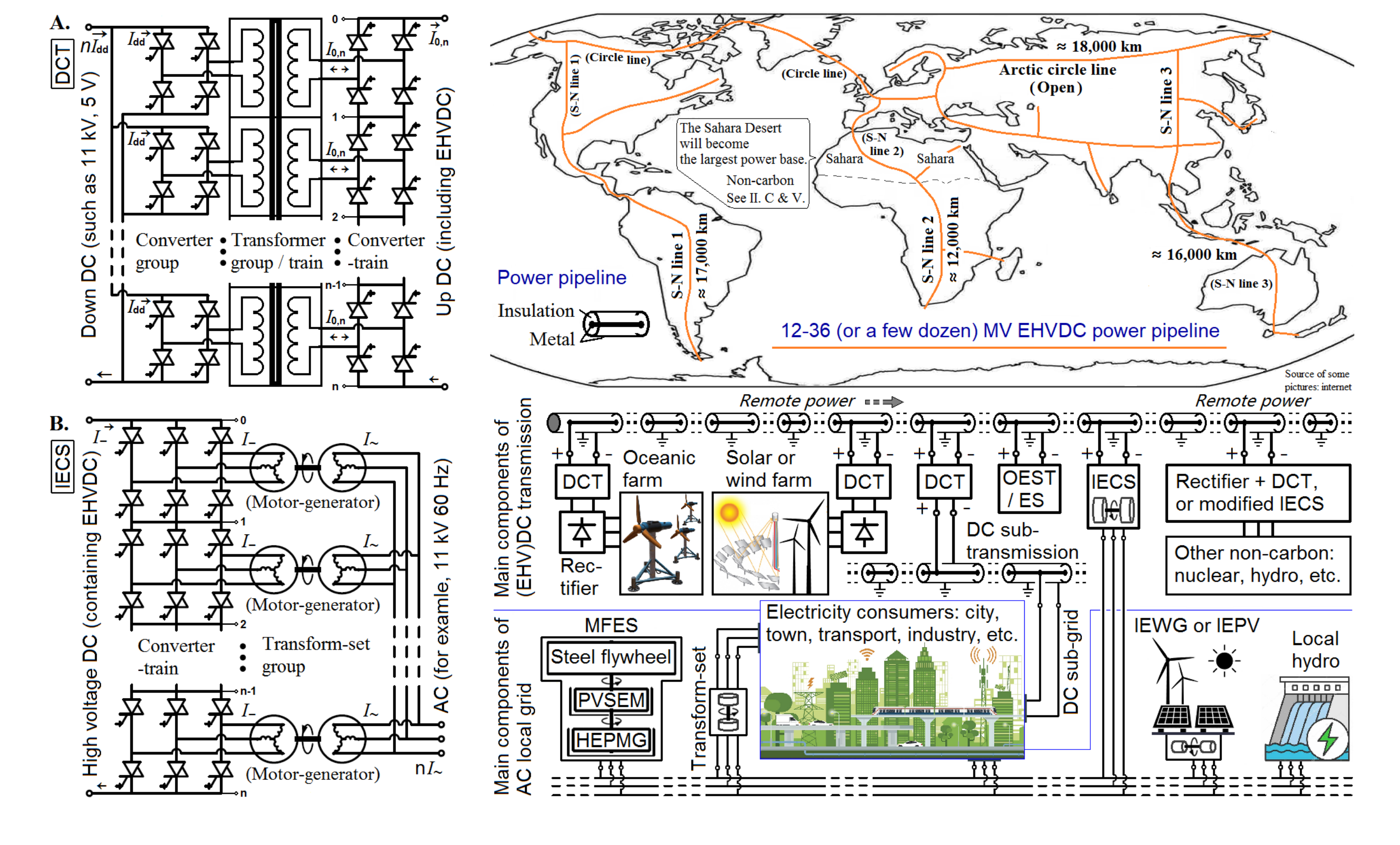

Figure 1: CFWPG configuration. (CFWPG – Carbon-free World Power Grid. 2 devices of pivotal technology: A. DCT – DC Transformer, also called DC convert-station; B. IECS – Inertia- endowed Convert-station. 1 MV = 10^3 kV = 10^6 V; EHVDC – Extremely High Voltage DC; ES – Energy Storage; OEST –Online ES Train; MFES – Multi-function Energy Storage, PVSEM – Pure Variable Speed Electric Machine, HEPMG – Hybrid Excitation Permanent Magnet Generator; IEWG – Inertia-endowed Wind Generation, IEPV – Inertia-endowed Photovoltaic generation; Transform-set, such as that of 11 kV / 440 V 60 Hz)

problems can be well solved with innovations and worldwide grid reconfiguration.

A. Converter-train: for Any Voltage or Any Multi-level

It is well known that the higher voltage means the higher efficiency and the longer distance to power transmission. EHVDC of a few dozen MV class can realize ultra-long distance or worldwide power transmission. In order to gain and adapt that high voltage, DCT and IECS, as shown as A. and B. of Figure 1, are proffered by complete reconfiguration with fully controllable power electronics, such as IGCT.

DCT can realize DC voltage either step-up or step-down. It integrates power electronics and conventional AC transformer into the topology in design. In same group or train, all converters share the common control signal and output power synchronously.

Here, the convert power *(P)* equation of DCT is

$$P = U_{dd}(nI_{dd}) = nU_{dd}I_{dd} = nU_{0,1}I_{0,n} = U_{0,n}I_{0,n} \qquad (1)$$

then, transformation ratio ($\mu_{\sim}$) of each transformer is defined as

$$\mu_{\sim} = U_{0,1} / U_{dd} = I_{dd} / I_{0,n} \qquad (2)$$

and DC transformation ratio (μ_{-}) of DCT is deduced as

$$\mu_{-} = U_{0,n} / U_{dd} = nI_{dd} / I_{0,n} = n\mu_{\sim} \qquad (3)$$

where, all units in same group or train own same parameters; n is the total number of units in each group or train; U_{dd} is Down DC voltage; I_{dd} is the current of each converter in Down DC group; $U_{0,n}$ is Up DC voltage; $I_{0,n}$ is Up DC current; each voltage drop $U_{0,1} = U_{1,2} = \ldots = U_{n\text{-}1,n}$ in converter-train.

IECS, with the same topology method, is mainly for voltage step-down with providing inertia to AC local grid. While, for voltage step-up of remote hydro or nuclear power plant, it will be more suitable than DCT via some modifications in topology. All converters share the common control signal and output power synchronously. Transform-set group inputs and outputs power synchronously.

In brief, similar to those of DCT, the convert power *(P)* equation of IECS is

$$P = U_{-}I_{-} = U_{\sim}(nI_{\sim}) \qquad (4)$$

And DC-AC transformation ratio (μ) of IECS is deduced as

$$\mu = \mu_{\sim} / n \qquad (5)$$

where, all units in same group or train own same parameters; n is the total number of units in each group or train; U_{-} is DC voltage; I_{-} is DC current; $U_{\sim}$ is AC voltage; ($I_{\sim}/1.73$ equals phase or line current) $I_{\sim}$ is the whole power current of each generator to AC side; $\mu_{\sim}$ is transformation ratio of each transform-set.

Advantages of DCT and IECS to the existing convert-station (additionally refer Figure 2):

1. Adequate inertia can be offered to stabilize AC local grid.

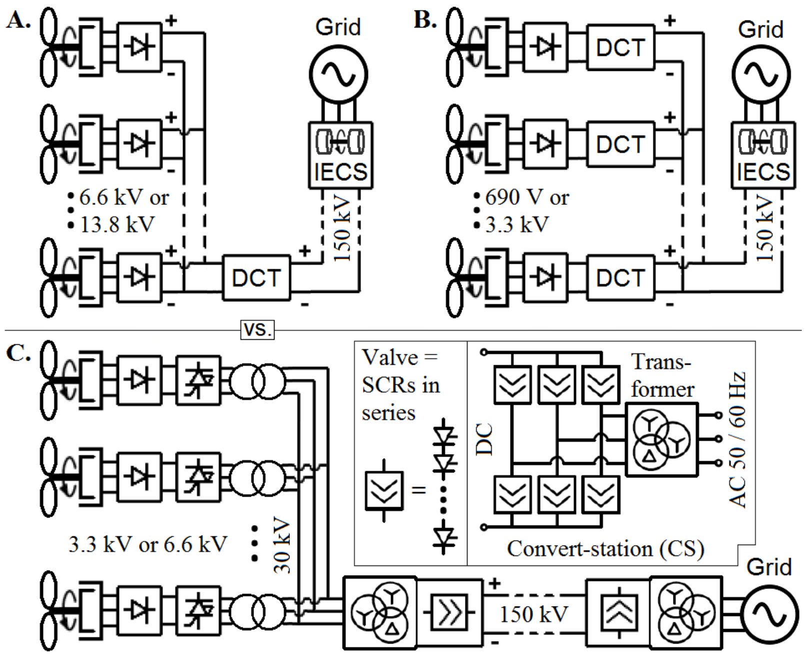

Figure 2: DC transmission comparison in wind generation: A. or B. DCT-IECS type; C. That of current convert-station. (Powertrain of A or B, in sequence: turbines, generators, rectifiers, DCT(s), DC transmission line, IECS and AC local grid. Powertrain of C, in turn: turbines, generators, rectifiers, inverters, transformers, CS, DC transmission line, CS and AC local grid).

2. Ultra-high transformation ratio can be realized.
3. Insulation design is not a trouble any more. DCT and IECS can even let EHVDC level reach hundred MV class via separating transformers / transform-sets.
4. The control circuit is much more simplified with fully controllable on-off and consumes quite less power.
5. More reliability and efficiency can be gained.
6. Adoption of SiC power electronics will be popularized.
7. Units will be fitter for modularization manufacture with smaller net size.

Present DC transmission, by comparison, converts electricity via conventional convert-station (namely, convert valve group and special transformer) as shown in C. of Figure 2, and can realize long distance transmission with more efficiency than AC. But it is only the auxiliary to today's AC grid, to transmit complement power from remote area to local.

OEST as shown in Figure 1 is the tech combination of IECS and MFES discussed in the next subsection. It also can be integrated into IECS, namely OEST-IECS.

Furthermore, in general purpose, converter-train will benefit the research of multi-level inverters for their popularization.

B. Supportive Technologies

Here, 6 of supportive technologies are listed as following: a. to c. for AC local grid; d. for low speed generation equipment; e. and f. for DC transmission.

a. PVSEM, as shown in Figure 3 or 1, feeds no harmonic back to grid, and will be the base technology of many new electricalsystems [3] [4]. It's essential soft-start ability is just that AC grid needs. As the substitute, it will be popularly applied in servo, fan or pump, (vehicle and vessel) electric propulsions, etc.

b. MFES, originally, is a technological solution scheme for smart grid of renewable energy. Besides PVSEM, techs of hybrid maglev, efficient vacuum and cooling are adopted [3]. Advantages of MFES device:

(1) Providing inertia to enhance grid resilience.

(2) High efficiency: the more volume will gain the higher efficiency (idling loss less than 1-4% per day).

(3) At least 20 years lifetime (no volume decline problem).

(4) The lowest cost among all kinds of energy storage (i.e. the most affordability: volume for household, some 100 kWh; for utility, more than several MWh).

To distribute MFES devices in grid will gain 3 functions:

(a) To ensure grid supply sufficient power and improve utilization rate of transmission line via charge-discharge balancing power supply-demand-peak-valley.

(b) To improve grid power factor smartly [3].

(c) To stabilize grid with inertia and continuous power: avoid potential blackouts as many as possible; quickly recover grid power after blackout [3].

In fact, MFES powertrain can be much simpler than the given in [3]. The updated scheme, as shown in Figure 1, contains no PMG (Permanent Magnet Generator) and no clutch; the final only comprises steel flywheel and special PVSEM-HEPMG.

c. Transform-set, including that of IECS, will reshape AC grid with its innate inertia and power factor adjustability. AC local grid of renewable energy needs the inertia to insure its resilience; however, transformer and converter cannot provide inertia, only

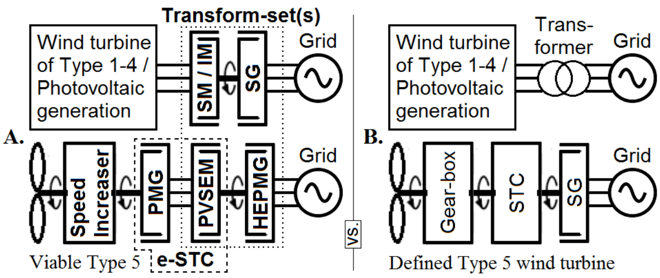

Figure 3: A. IEWG Type 1-5 and IEPV; B. Defined wind turbine generator Type 1-5 [5] and photovoltaic one. (SM – Synchronous Motor; IM – Induction Motor; SG – Synchronous Generator; STC – Speed / Torque Converter)

synchronous Electric Machine (EM) can, and common shaft bi-EM (transform-set) can also realize voltage transformation. Hence, transform-set substituting transformer will solve the grid stability problem, like frequent blackout accidents in South Australia [4], when thermal power plants are discarded. Moreover, transform-set can prevent reactive current and harmonics from being transmitted along AC grid line.

In virtue of transform-set (also named convert-set in [3] [4]), IEWG and IEPV mentioned in Figure1 are shown in Figure3.

d. Speed Increaser, here, is not that gear-box applied in wind generation, and can substitute the later. Generally, giant wind power plant, like GE Haliade-X 12 MW or Enercon EP5 5 MW, has to adopt direct-driven powertrain and outsize PMG because quite low speed has caused huge torque and unacceptable excitation loss of conventional generator. The bulky PMG has resulted in much higher cost in manufacture, carry and hoisting. However, Speed Increaser can change the status. It will reduce generator stator-rotor volume 60-90%, get expected efficiency 98-99.5%, and own much more reliability and quiet than gearbox. Its application can be extended to other low speed occasions, like oceanic and fluvial power plants.

e. Power pipeline, as shown in Figure 1, is a concentric naked “cable” with insulation between core conductor inside and conductive pipe outside for distribution under, semi-under or on the ground (or water). It can avoid electromagnetic pollution, electric shock, failures by bad weather, and so forth those are disadvantages of present DC transmission with overhead line.

f. DC Breaker, here, is a pure soft switch, with no electric arc at any time. This technology can also be applied to AC breaker and some other kinds of switches. The key is how to extinguish the arc, particularly under EHVDC. The methods have been researched out to let the arc disappear during the whole on-off process. Note that it is not based on power electronics.

C. Integrations in CFWPG and Advantages

Via inertia reconfiguration with IECS, all remote power sources, like oceanic and wind farms, nuclear and hydro power plants, can supply power to AC local grid through (EHV)DC transmission mainly by advantage of the lower transmission loss. DCT can connect 2 different voltage level DC lines. IECS can directly connect AC local grid and CFWPG or regional DC transmission line. ICES will be the optimum interface between AC and DC: to provide inertia to AC local grid; to produce no impact on DC line. AC local grid as the basic supply unit can be big or small in scale. IECS, MFES and inertia-endowed renewable energy generation will change the status that current AC grids depend on thermal power plants providing inertia and continuous power, and realize green energy Smart Micro Grids.

Owing to one-way characteristics of rectification, the remote generation will output power as soon as it can: all generators absorb no power from grid at any time; the speed of each generator can be asynchronous and variable to gain optimal efficiency. Whereas in AC transmission, synchronous power current is bidirectional, generator will become motor to absorb power from grid as soon as the drive disappears.

CFWPG will essentially reduce energy sources’ waste a lot. Transient energy, like tidal, even lightning, can be collected and stored in OEST or MFES. Sahara, as marked in the map of Figure1, will manifest its value for solar and wind energy sources.

D. Electricity Cost

How can electricity get sufficient low-price? Obviously, long lifetime and high reliability (i.e. demanding maintenance as little as possible) of all power facilities are the decisive. It is expected that lifetime of each device or facility listed in Figure 1 will be more than 20-40 years.

Flywheel lifetime of OEST or MFES is at least 20 years or 10^6 cycles (2,740 years if 1 cycle per day) that is given in quite a few references including those listed in [3], much longer than any battery. In volume and lifetime, flywheel has no decline problem to temperature or overload. Hybrid maglev will ensure much less maintenance, lower manufacture cost and higher efficiency. Among all kinds of energy storage, OEST or MFES will keep the highest efficiency.

Transform-set can be directly integrated with hybrid maglev in design to ensure its lifetime, efficiency and less maintenance.

Lifetime of Speed Increaser will be more than 20 years, mainly up to speed ratio.

SiC power electronics is much more than that of silicon in efficiency, lifetime and reliability.

NON-CARBON TRANSPORT BASED ON CFWPG

Transport is the next main carbon emission source because most of vehicles depend on carbonaceous fuels to generate power. Though current (H)EV, electric highway and electric propulsion of vessel have reduced some emission, the problem still exists. Hence here, 2 economic methods of zero carbon emission transport are discussed on account of CFWPG.

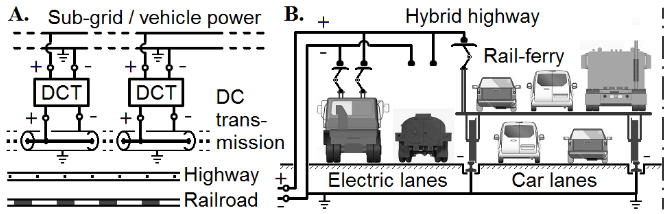

Figure 4: A. DC transmission along traffic lines; B. Rail-ferry hybrid highway

A. Rail-ferry

Dedicated rail-ferry line with hybrid into main highway is shown as B. of Figure 4. Volume of rail-ferryboat can be same as that of ferryboat. Wide rail gauge is recommended for swaying as little as possible and full utilizing interspace. Rail-ferryboat can carry bus, truck, tractor and others. Vehicle driver will own the opportunity to take a rest and charge (H)EV during the carry time. In addition, rail-ferry will potentially reduce traffic accidents. The maximum speed of rail-ferryboat should be more than 150 km/h.

By the way, it is a reasonable suggestion to distribute DC transmission line along highway and railroad.

B. Electrolytic Hydrogen

For hybrid power, fuel cell and battery will be the optimum partner. Though fuel cell is usually poisoned by sulfides during getting oxygen (O_2) from air at present, the problem can be well solved. Surplus non-sulfide oxygen will be supplied. On the one hand, both O_2 as oxidant and hydrogen (H_2) as fuel can be made of water (H_2O) as the following chemical equation:

$$H_2O \xrightarrow{electrolize} H_2\uparrow + \frac{1}{2}O_2\uparrow \quad (6)$$

On the other hand, the new methods of metal production discussed in the next section will produce quite a bit of extra O_2. Therefore, fuel cell will be popularly applied in both HEV and vessel. Furthermore, H_2 is the initial fuel of rocket, and can also be supplied to airplane engine.

OTHER SECTORS' 0-CARBON EMISSION UNDER CFWPG

Carbon has been advancing the progress of human society. As it were, there is "no carbon, no life". 2 basic usages of carbon are: as material or chemical ingredient, like Graphene, carbon fiber, food and wood; as fuel to generate heat or power, but emit CO_2 at the same time.

A. Carbon-free Heating, Cooling and Lighting

Non-carbon heat substituting the carbonaceous will be a breeze when CFWPG provides sufficiently low-priced power, though present heat is almost generated from carbon for cooking and heating in home, chemical industry, cement production, even stockbreeding, etc. It will be unnecessary to excessively depend on carbon energy any more.

Low-priced carbon-free electricity can realize liquid nitrogen (N_2) or other liquid gas substituting the current refrigeration. Cheap non-carbon power will provide cultivation with sufficient light to increase production and absorb more CO_2.

B. Carbon-free Metallurgy

At present, as heating fuel, deoxidizer and ingredient, quite a little carbon is consumed during the whole process from pig iron production to steelmaking, and almost becomes CO (carbon monoxide) and CO_2. This whole process also includes coke-making and desulfuration. It is complicated obscenely. And 2 basic equations of chemical reaction are as following:

$$C + \frac{n}{2}O_2 \xrightarrow{ignite} CO_n \quad (7)$$

Where, C is carbon element, n = 1, 2, and

$$Fe_2O_3 + \frac{3}{2}C \xrightarrow{heat} 2Fe + \frac{3}{2}CO_2\uparrow \quad (8)$$

Where, Fe_2O_3 is ferric oxide, Fe is ferrite element.

Nowadays electrolytic aluminum production emits CO_2, CF_4 and C_2F_6 (carbon tetrafluoride and dicarbon hexafluoride, own much more greenhouse effect than CO_2) from carbonic graphite anodes, though it has no use for fuel, deoxidizer and ingredient at all. The main equation of chemical reaction is

$$Al_2O_3 + \frac{3}{2}C \xrightarrow{electrolize} 2Al + \frac{3}{2}CO_2\uparrow \quad (9)$$

where, Al_2O_3 is aluminum oxide, Al is aluminum element.

It is encouraging that, however, research of inert anode materials has been going on and will realize

$$Al_2O_3 \xrightarrow{electrolize} 2Al + \frac{3}{2}O_2\uparrow \quad (10)$$

Hence, carbon-free aluminum production will come.

As to carbon-free iron-steel production, 2 new methods are discussed as following.

Option 1: Aluminothermy

Aluminothermy is usually used to gain liquid steel to weld 2 rail sections during railroad building. The liquid steel contains no impurity, such as sulfur which originally comes from coke or coal during pig iron production. So, aluminothermy will be much more advantageous than the current production method when electrolytic aluminum is gained on a large scale through inert anode successfully. The equation of chemical reaction is

$$Fe_2O_3 + 2Al\ C \xrightarrow{ignite} 2Fe + Al_2O_3 \quad (11)$$

and its production diagram is shown as Figure 5.

Option 2: Electrolyzation

As the new way to gain aluminum, the chemical equation

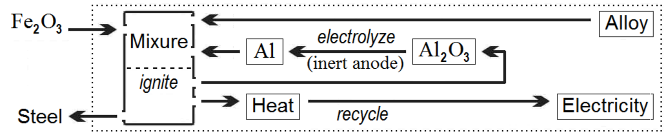

Figure 5: The main process of steel production with aluminothermy

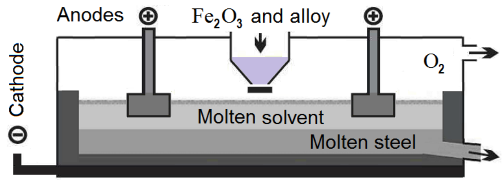

Figure 6: The sketch of electrolytic steel production

$$Fe_2O_2 \xrightarrow{electrolize} 2Fe + \frac{3}{2}O_2 \uparrow \quad (12)$$

has long been published. And the similar production sketch is given as Figure 6. Melting points of pure iron and Fe_2O_3 are 1538 °C and 1539 °C respectively. Fe_2O_3 itself should be the suitable solvent. If it is viable, the production process will be the simplest and cleanest.

In practical production of aluminothermy or electrolyzation, all materials will be made into grains or powder. As an option, via inserting a pipe into liquid steel, inert gas, CO or maybe methane (CH_4) can carry and blow the powder of alloy materials into the liquid.

DISCUSSION

Though zero carbon emission is only discussed here, clean fuels like methane (CH_4) should not be emitted wastefully. To EHVDC power pipeline, 12-36 MV should be reasonable, while the thicker insulation for the higher voltage will be more suitable to apply superconductor for less refrigeration.

As to CFWPG, it is more feasible to start with largish region power grids, like those listed in [6], or maybe the proposal "First Steps to a Global Supergrid" [6] is more reasonable. Largish region grid with adequate components listed in Figure 1 should basically fulfill zero carbon emission.

Sometimes, the extra-surplus power will emerge in CFWPG, for instance, that from energy farms in Sahara, can be locally used to irrigate artificial oases, not only for absorbing CO_2, or be used in water diversion somewhere. So, overfull installed capacity in CFWPG will gain extra benefits.

For certain applications of DCT and IECS, some integration is needed; diode is an additive or substitution in topologies.

To keep the livable globe, production and life modes must be upgraded to get zero carbon emission; carbon-free in all sectors deserves research and investment; additionally, the massive waste plastic/rubber around the globe can be well recycled as the insulation filling of power pipeline.

CONCLUSION

This paper has basically proved zero carbon emission fully viable. Electricity is the key: converter-train has been proffered to construct DCT and IECS to constitute Extremely High Voltage DC transmission and its interface with AC local grid, and together with supportive technologies to configure Carbon-free World Power Grid to offer low-priced electricity sufficiently. Carbon-free solutions in other sectors (transport, industry, etc.) have been discussed under non-carbon power.

REFERENCES

1. Elizabeth Kocs, et al., "The global carbon nation: Status of CO_2 capture, storage and utilization," European Physical Journal Web of Conferences, pp. 1-16, July 2017, 10.1051/epjconf/201714800002.
2. IEA (International Energy Agency), "Transforming Industry through CCUS," Technology report, May. 2019. [Online]. Available: https://www.iea.org/reports/transforming-industry-through-ccus.
3. Jianlong Bai, "Multi-function Energy Storage System for Smart Grid," IEEE Green Energy and Smart Systems Conference (IGESSC), Long Beach, USA, 2019, pp. 1-4.
4. Jianlong Bai, "Grid Inertia Reconfiguration Strategy and Tech Solution Suggestions for South Australia Blackouts," in ICPES2019, Singapore, Springer, pp. 47-58.
5. IEEE PES WPCSDWG, "Characteristics of Wind Turbine Generators for Wind Power Plants," IEEE Power & Energy Society General Meeting, Calgary, Canada, 2009, pp. 1-5.
6. Clark W. Gellings, "Let's Build a Global Power Grid," IEEE Spectrum, Jul. 2015. [Online]. Available: https://spectrum.ieee.org/energy/the-smarter-grid/lets-build-a-global-power-grid

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