A Review of Long-Distance UHVDC Technology - A future Energy Disrupter

Innocent E Davidson
Department of Electrical Power Engineering
Durban University of Technology
Durban, 4000, South Africa
innocentD@dut.ac.za

***Abstract*—It is proposed to use highly complex power system controllers to integrate African power grids into one super-grid that can accept large penetration of renewable powers, without compromising power quality, active and reactive power flow, and voltage and power system stability. The proposed super-grid constructed with ultra-high voltage direct current (UHVDC) and flexible ac transmission systems (FACTS) along with dedicated ac and dc interconnectors with intelligent systems applications to produce a Smart Integrated African Super-Grid. DC interconnectors will segment the entire continent's power systems into five large asynchronous segments (regions). Asynchronous divisions will prevent ac fault propagation between sections while allowing power exchange between different parts of the super-grid, with minimum difficulty for grid code unification or harmonization of regulatory regimes across the continent as each segment maintains its autonomy. A Smart Integrated African Electric Power Super-Grid powered by these technologies is critical in supporting Africa 's sustained economic growth and development; established on the cornerstone of renewable energy and utilizing over 200GW enormous potential of Africa's clean and renewable hydroelectric, photovoltaic and wind power as a portion of a vast energy mix made of traditional and complementary energy resources.**

***Index Terms*—Super-Grid, HVDC, DC Interconnectors.**

I. Introduction

The very last century has shown that every aspect of technological evolution, including the 4th Industrial revolution, is built along with an uninterrupted and secure electricity generation regime [1]. The population of Africa has grown significantly from 364 million in 1970 to nearly 800 million in 1999. This population is projected to reach 1.3 billion by 2020. As a percentage of the overall world population, Africa has increased by 10 percent in 1999 from over 13 percent in 1970, and expected to reach 17 percent by 2020. Africa is fast becoming the next big major player in the industry, overtaking China [2]. Data from China's Ministry of Commerce suggests that Africa's population may hit 2 billion by the year 2050, forming the world's biggest labor pool. [2].

II. Energy Landscape

The changing global environment has witnessed the 1st industrial revolution with mechanical production in the 1800s based on coal (fossil fuels) to the 2nd industrial revolution in the 1900s with the use of electrical energy. The 3rd industrial revolution in the 2000s was based on the use of information and communications technology to further computerize production. The 4th industrial revolution (4IR) is based on the use of cyber-physical systems. (See fig 1). Similarly, the features of future energy show a shift:

- Towards the DC power grid
- Low carbon future
- Carbon-neutrality (new power generation projects)
- Greenhouse gas (GHG) emissions standards
- Universal electrification: energy access, affordability.
- Sustainability
- Advances in cutting edge VSC-HVDC technology
- Smart Infrastructures.

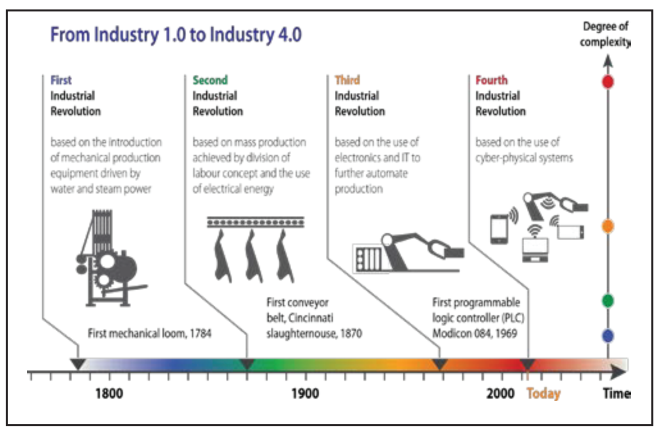

Figure 1. The Changing Global Industry Environment.

During the transition into the 21st century, the world has had significant developments that have prompted radical changes, including automation (robotics and integration), the emergence of the digital high-speed line, and globalization. There's been a change from analog to digital technologies, sub-militarisation, ultra-learning (and distance learning), e-commerce, networking technologies (multi-media), shifting markets, and an explosion of consumer products and goods on the market. Such trends and advances in technology have impacted Africa. Society, national, and social security organizations are highly dependent on the availability of

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energy supplies. There is a clear link between the per capita gross domestic product (GDP), per capita energy consumption, and every society's standard of living.

III. Economic Success in the 21st Century

For Africa, Engineering Technology is most essential for economic success. It is, therefore, imperative to train more engineers, scientists, technologists, technicians, and artisans in the lucrative and exciting fields of engineering, which is the backbone of our modern economy and the largest employer of labor. Electricity is the key driver of the global economy. It is the prime energy resource for supplying customers, because of its transmissibility (easy to transport in bulk quantities over long distances), versatility (natural to convert to other forms of energy), and ease of control. It is nevertheless the preferred source of energy for supporting industrial, commercial, and residential loads.

The availability of inexpensive and abundant energy is vital to mechanized agriculture, mining/industrial manufacturing, modern transportation, and physical comforts. Society organization, national security, and social security depend on the availability of energy supplies. There is a useful link between GNP per capita and consumption of energy per capita and living standards. Energy security is critical to national security; hence its' availability is crucial to economic growth and development.

Economists generally agree that there are five essential pillars of economic success for any nation in the 21st century, namely:

- Very educated and distinguished community
- Extremely advanced technology
- Rich new, highly productive agrarian base
- Large deposits of energy resources
- Ample availability of energy-free materials

Africa has had the world's lowest per capita energy thus far. That makes energy deprivation one of the critical causes of the continent's economic stagnation. Given that electricity is the driver of economic development and sustainability. Consequently, concerted efforts and ambitious spending on infrastructure that promote international trade across the continent are crucial. This begins with a "Smart Integrated African Electric Power Super-Grid" (figure 2) propelled by advanced equipment and breakthroughs in High Voltage Direct Current (HVDC) technology [2] and Flexible Alternating Current Technology (FACTS) devices, which would be central to stabilized economic and social development in Africa.

Africa's energy challenges are global problems and do require integrated solutions. These nations must face their most significant obstacle in reshaping their economic systems from resource-based to productive and knowledge-driven economies. This includes taking full responsibility for resources, transforming markets, developing intelligent infrastructure, investments in education, human resources, and creating an attractive atmosphere for direct domestic and foreign investment to flourish. Investing in human resources thus developing a critical mass of skills on the continent is a strategy for national governments to be a major player in international marketplace. We must therefore prepare, build and supply Africa with highly competent, valuable and skilled professionals who understand the profession's new and existing issues, namely: generating, transporting and distributing electrical energy to serve consumers efficiently , safely, financially and efficiently, in a changing smart utility environment.

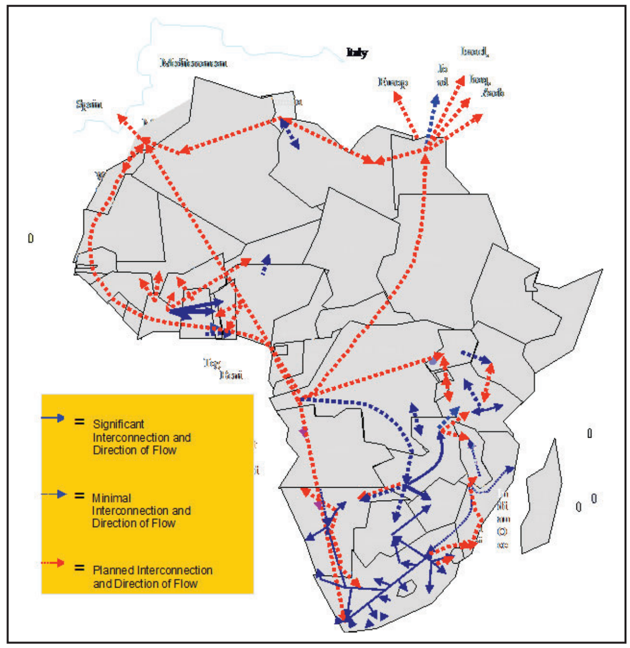

Figure 2. A Smart Integrated African Electric Power Super-Grid

IV. Long Distance UHVDC Technology

IEEE Spectrum [3], 10 January 2019, China's primary national grid estimates a 1.1-million-volt direct current (DC), which crushes world records of voltage, long-distance, and power. The latest generation Ultra High Voltage DC (UHVDC) line installed by State Grid Corporation in Beijing will deliver up to 12 gigawatts (~10% of Africa's total generation capacity) [4]. According to a statement issued by China State Grid, that is enough to power 50 million Chinese households and fifty percent far more than the 800-kilovolt UHVDC lines installed by State Grid in the last ten years.

The latest 1100 kV UHVDC line integrates the alternating current of the grid at an AC / DC converter station near the capital of Xinjiang — the vast Northwestern region of China — and transfers DC power to a second converter station in the province of Anhui in eastern China. The 3293 km run stretches the world distance record for the electrical power transmission by more than 900 km. This can end up replacing the equal amount of a coal-fired generation worth of 25,000 coal trains in highly polluted eastern cities in China. It substantially helps reduce greenhouse gases and ameliorates air pollution when the state grid operator prioritizes exports of the plentiful solar and wind resources in northwest China [3].

Fig 3 shows the existing regional power pools in Africa, divided into 5 asynchronous regions.

Figure 3. African Super-Grid with asynchronous segments/regions

Fig. 4 shows the largest untapped hydroelectric resource in the world, The Congo River, at the heart of Africa – The Grand Inga Hydropower potential. The Congo River is overall 4,370 km long (2,715 mi). It is the world's sole river to cross the equator two times, providing for all year round of rainfall. The Congo Basin has a net area of approximately 4,000,000 km^2 (1,500,000 mi^2) or 13 percent of Africa's total land area. The Congo River (Grand Inga and tributaries) has a combined hydro potential of 50000 MW. A coordinated upper and lower stream dam for optimum hydropower generation can yield ~ 100000MW capacity of sustainable, clean, green renewable energy. This is equivalent to the combined installed electric power generation capacity of Africa currently. At a tariff of US$0.01/kWh, it will ensure Africa's universal electrification, and excess for European export. This requires an Energy Marshall Plan for Africa. Combining the hydropower, solar-PV and wind power resources in Africa, provides sufficient electricity exports to all the regional power pools, namely: West African Power Pool (WAPP), North Africa Power Pool (NAPP), [5], East African Power Pool (EAPP), Central African Power Pol (CAPP) and Southern African Power Pool (SAPP). This paper proposes to use highly complex power-system controllers to integrate African power grids into one super-grid that can accept large penetration of renewable powers, without compromising power quality, active and reactive power flow, and voltage and power system stability.

Figure 4. Africa's Untapped Grand Inga Hydropower Potential

The proposed Smart Integrated African Electric Power Super-Grid constructed with ultra-high voltage direct current (UHVDC) and flexible ac transmission systems (FACTS) along with dedicated ac and dc interconnectors and smart grids. DC interconnectors will segment the entire continent's power systems into five large asynchronous segments (regions). Asynchronous segments will prevent ac fault propagation between segments while allowing power exchange between different parts of the super-grid, with minimum difficulty for grid code unification or harmonization of regulatory regimes across the continent as each segment maintains its autonomy.

A Smart Integrated African Electric Power Super-Grid driven by these technologies is crucial to facilitating Africa's continued economic development and growth; established on the core component of renewable energy and utilizing the untapped potential of Africa's cleaner energy solar-powered hydropower and wind energy as a percentage of a massive mix of traditional and complementary energy resources [6]. This will jumpstart the global economy for the next century.

IV. HVDC TECHNOLOGY

It is the strategic intention or objective of several African electric utilities to use high HVDC technology extensively at some point in the future. HVDC systems offer several operational and special technical advantages over HVAC transmission systems. HVDC power has no frequency, hence limited complications with the harmonics, oscillations, or transients;. All angular stability problems disappear, and even the connection of systems at different frequencies is feasible. HVDC eliminates cable charging current issues, thus making cables an excellent choice for underwater crossings. With weak AC grids, converter-based voltage source HVDC systems give flexibility, controllability, and grid stability to integrate intermittent generation, such as wind and solar power [7].

Using power electronic switching devices or FACTS Controllers, accurate and quick regulation of power in any direction is more straightforward to implement in HVDC than in HVAC schemes. Reactance minimally affects dc power. The simplicity of power flow control in HVDC networks makes it much easier for transmission lines to reach optimum power and thermal efficiency. And it's also easy to monitor active power transfer at a specified value or even modulate this to enhance the damping of the device.

HVDC transmission has hitherto been an alternative to overcoming the limitations of HVAC transmission [8]. Still, it is now the developed technology of choice for long-distance transmission, marine electrical transmission systems, and intermittent AC grids of different frequencies interconnection. HVDC design is rising as an addition to AC transmission, outside its conventional role. This plays a vital role in electrical power grid revitalization (Smart Grids). The introduction of low and medium voltage DC distribution grids and the integration of renewable energy into the grid [9]. These emerging trends are essential to African electric utilities and municipalities, as they shape the electricity industry in Africa.

V. HVDC RESEARCH

The electric power system is experiencing significant structural changes in this age of innovation and enormous technical advances. Key drivers include network reliability, environmental, climate, regulatory and economic challenges, and the crucial objective of lowering transmission/distribution losses. HVDC is a long-established solution provider for the long-distance transmission of enormous electricity. It also plays a critical role in the grid integration of intermittent renewable energy sources using power electronics [10]. HVAC electric power grids can be enhanced using HVDC kinks [11].

Around the world, several projects and research initiatives are investigating these developments using HVDC technology and the impact of HVDC power transmission on grid stability and electrical power systems efficiency in this emerging SMART utility context. Clean energy zones in Queensland-A effectively integrating infrastructure development for generation and transmission [12], and the implementation of cost-effective grid-scale energy storage as a facilitator of sustainable energy network integration [13].

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