Sahara Desert Interconnected DC Network

Giddani Kalcon, Abdelaziz Y. M. Abbas, Aamir Hashim Obeid Ahmed, Nagm Eldeen Abdo Mustafa Hassanain

Abstract— The main objective of this paper is to build regional interconnected DC network extended through the upper part of Africa including Sahara desert in order to maximize the utilization of distributed generation such as solar energy in Sahara desert and wind power in the Mediterranean and the atlantics. The paper also develops friendly integrated techniques to connect the wind farm and solar projected into DC network pool according to standard grid codes without creating operational or stability problems. The paper addresses the challenges of the power mismatch and frequency instability emerges due to nature of renewable power units and the power trading between the regional networks and the dc power pool.

Index Terms— DC interconnected network, Distributed generators, frequency stability, and VSC converter.

————————————— ◆ —————————————

1 INTRODUCTION

THE wide globally trend to reduce CO2 emission and mitigate global warming require installation of new large generation units based on renewable sources to replace conventional generation stations.

Also the utilization of renewable power represents an economical alternative in areas with appropriate renewable resources and during shortness of oil and coal. In most parts of the world renewable energy supplies only a fraction of the total power demand, if there is any alternative generation production at all, but in some of European countries wind power penetration represent appropriate amount of total generation. In Africa and Middle East (especially in Sahara desert and Arabian Peninsula) the solar energy is available almost all the year but no large solar plant has been installed yet. Also the wind power is available in the Red Sea and the Mediterranean but the use of these resources is growth very slowly because the required technologies are very expensive, beside the absence of financial support from government and international organization to support the renewable power researches.

The use of distributed resources is one of the important option for solving climate change issues and energy security problems. The concept of decentralized electrical power systems based on clusters of distributed renewable plants such as wind, solar, biogas is well suited for accommodation of large number of renewable power plants distributed over a wide area without significantly compromising the reliability and security of the energy supply [1-3]. The interconnection of widespread wind farms and solar energy projects to a common dc network reduce the possibility of renewable power variability because of correlation of different weather conditions. The addressing of fluctuating supply in renewable generation based on the idea that many fluctuations will eventually cancel each other out in a wide area supply. In widespread area the wind potential is high somewhere while the sun is shine somewhere in the same area. Incorporating of distributed battery energy storages system (BESS) within the interconnected system will eliminates the remaining fluctuation.

For economical and technical reasons regional interconnected power systems are extended hundreds of kilometres to cover wide area. The largest interconnected power network in Europe is the ENTSO (European Network of Transmission System Operators for Electricity) which uses AC transmission to interconnect 34 European countries.

The construction of the backbone of the regional transmission system can be built using the high voltage ac system (HVAC) or high voltage dc system (HVDC). The HVACs are well-known technologies, proven, cheap and reliable but with the increase in the power capacity and the long transmission distance between the regional networks, the HVAC technology face some technical limitations which could reduce the advantages of the interconnected system.

A VSC-HVDC system is a suitable technology for building the super-grid dc network. It is easier to control the power flow and build parallel multi-terminal configurations. Simple fixable control system is associated with multi-terminal operation including power management and power reversal. VSC-HVDC facilitates the connection of renewable power plants and isolated islands to the dc network. In general, the potential benefits of DC interconnected power system are summarized as follow [4-5]:

- Allow optimum use of available resources and reduced the generation cost by optimal unit commitment.
- The connection of widespread renewable energies to common network reduces the possibility of power variability.
- Facilitates power trading between the regional ac networks over long distances with optimum transmission losses.
- Decouple operation of individual network via DC network prevent fault propagation from network to other

————————————————
- *Giddani Kalcon. School of Electrical and Nuclear Engineering, College of Engineering, Sudan University, Sudan, E-mail*
- *Abdelaziz Y. M. Abbas. School of Electrical and Nuclear Engineering, College of Engineering, Sudan University, Sudan, E-mail: abdelazizyousif@sustech.edu, abdelaziz.abbas67@gmail.com*
- *Aamir Hashim Obeid Ahmed, School of Electrical and Nuclear Engineering, College of Engineering, Sudan University, Sudan, E-mail aamirahmed@sustech.edu, aamir_elec@yahoo.com.*
- *Nagm Eldeen Abdo Mustafa Hassanain. School of Electrical and Nuclear Engineering, College of Engineering, Sudan University, Sudan, E-mail: nagmabdo@sustech.edu, nagmabdo1@gmail.com,*

- The inherent reactive power capabilities of the VSC converter provide the necessary reactive power compensation and limit the overload in the system.

This paper investigate the possibility to build regional interconnected DC network extended through the upper part of Africa including Sahara desert in order to maximize the utilization of solar energy in Sahara desert and wind power in the Mediterranean and the atlantics. These include the installation of the distributed generators based on wind and solar energies and the suitable integrated techniques to inject the power into DC network (power pool).

Energy storage systems are installed to achieve the power balancing and stabilize the frequency variation due to nature of renewable power units and the power trading between the regional networks and the dc power pool.

Section 2 highlights the construction of DC interconnected network and the methods used to connect the deferent components in the common power pool. In section 3 the proposed lay-out is investigated to implement the concept of the DC network with the various renewable sources and BESS. The technique for controlling the network with central and local control is discussed in section 4. While the obtained results are analysis is section 5. The challenges which face the construction of the Sahara network are investigated in section 6. Finally the conclusion is briefed in section 7.2 Procedure for Paper Submission.

2 THE CONCEPT OF INTERCONNECT

In interconnected electrical network, the dc network composes of multiple buses connected together with dc lines to form interconnected grid. The power injection into the dc pool or power withdraw from the dc network is done using power converters. The using of fully controlled converters is necessary to ensure high reliable and stable system. BESS is connected to AC network using full controlled power to achieve power balance between the dc and the ac sides. In this case the AC networks are built using conventional power plant based on fossil energy and deceneterlaztion renewable plants. The dc interconnected network must be accessible so that any AC network can be connected into the system. The dc network in this case represents power pool capable to accept dc power injection or withdrawal from AC networks.

In general the interconnected network should meet the following requirements [6-7]:

1- Self-healing from power disturbance events.
2- Clean and green: increased penetration of renewable energy reduces greenhouse gas emissions.
3- Reliability and security: improve power security to customers during network disturbances.
4- Flexibility: expandable and must be able to operate in grid-connected and islanding modes.
5- Frequency stability: this requires sufficient energy storage systems to achieve power balance during event of power variation, peak demand and reconnection of generation areas.
6- Power quality: FACTS devices may be used to maintain the voltage at transmission and distribution levels, and improve power quality.

7- Economy: efficient power management reduce the energy cost by reducing system losses, power plant scheduling, storing power and releasing at peak demand, etc.

2.1 Connection of wind farms

Offshore wind farms always located far away from the shore collection point. As a result the need has increased to develop strong effective methods to transfer the generated offshore wind power to the nearest power network access point. The integration process of wind farms into power networks faces two challenges: collection of the wind power at the offshore collection point, and transmission of the collected power to the onshore collection point. At present, the two established wind turbine generator technologies are fixed and variable speed. The variable wind turbines are based on doubly fed induction generator (DFIG). The DFIG consists of a wound rotor induction generator with the stator winding connected directly to the ac network, while the rotor windings are connected via back-to-back partial scale power electronic converters. The power electronic converter decouples the mechanical and electrical frequencies and makes it possible for variable speed operation.

The DFIG could adjust the rotor speed in order to maximize the wind power extraction over a wide range of wind speeds. Furthermore, they can absorb any fluctuations and eliminate the flickers in the generated power and voltage due to the variation of wind speed [8].

Wind energy development in Africa is very slow. Most projects require financial and technical support from international aid organisations, as there is only limited regional support. Wind installation projects are planned in Morocco, Ethiopia, Tunisia and Egypt.

Morocco is the leading country in wind power generation in Africa. The Moroccan Integrated Wind Energy Project launch strategic plan to increase wind power penetration to 14% by 2020. The plan increases the installed capacity from 280 MW in 2010 to 2000 MW in 2020. The development of 1720 MW of new wind energy farms are planned to installed as follow:

- ❖ Tanger2 (150MW)
- ❖ Boujdour (100 MW).
- ❖ Taza (150 MW)
- ❖ Tiskrad Laayoune (300 MW)
- ❖ El BaidaKoudia in Tetouan (300 MW),

Egypt has also a high potential for wind energy, especially in the Red Sea coast area. As of 2013, 550 MW of wind with a target to reach 7200MW by 2020 which is 12% of total electric capacity. In 2015 Siemens sign contract with Egyptian government to install additional 2GW of wind power in Egypt.

TABLE.1: Wind power potential in Sahara countries

	Installed by 2013(MW)	Planned by 2020(MW)
Egypt	550	7200
Morocco	495	2000
Tunisia	104	
Ethiopia	171	800

2.2 Storages energy systems

In the last 50 years a lot of researches are conducted in energy storage systems. This resulted introduction of several storage technologies into power systems to provide ancillary services such as pumped hydro, flywheel, compressed air and batteries system. An energy store theoretically will absorb the energy when the generation is high and the load demand is low. When the demand goes up and exceeds the generating capacity the store will release the required quantum of energy. This has multiple advantages such as [9-10]:

1. It supports power quality on the voltage and frequency.
2. It improves the reliability, upgrading the power quality indices such as SAIFI and SAIDI.
3. It enables a higher penetration of the renewable energy sources. This is an important aspect, particularly when all over the world strong efforts are being made toward going away from the fossil fuels to renewable energies.
4. With a market-based structure, it helps to utilize optimally electricity production, whether from conventional sources or from nonconventional sources.
5. Stores help us on the emission front by increasing gains in carbon credits for reducing objectionable gases, thus reducing use of fossil-based fuels.

The BESS is normally interfaced to grid using bi-directional power flow converters that use dc link capacitors to decouple it from additional stresses during ac networks disturbances.
The BESS achieves power levelling and stabilizes ac network frequency through adjustment of its output active power exchanges with the ac network.
The additional benefit of using power electronic converter for interfacing the BESS into main grids is its ability to act as STATCOM in order to regulate AC voltage. The BESS is stabilizes the system frequency, regulate the bus voltage and to restraint the ac current injection to the AC network during disturbances [11].

2.3 Connection of Solar Units

Solar energy is the most abundant energy resource in the earth, the solar radiation reaching the earth's surface equals about 1 kilowatt per square metre (kW/ m²) in clear conditions when the sun is near the zenith. The current technology used to benefits from solar resource is using of concentrating solar thermal plants (CSP). The CSP plants concentrate solar rays to heat a fluid, which then directly or indirectly runs a turbine and an electricity generator. Concentrating the sun's rays allows for the fluid to reach working temperatures high enough to ensure fair efficiency in turning the heat into electricity while limiting heat losses in the receiver. The dominant CSP technologies are [12-13]:

1- Parabolic troughs collector (PTC): Parabolic trough collectors (PTC) use single axis sun tracking algorithm to follow sun trajectory using highly reflective glass mirrors. PTC utilise oil heat exchanger medium.

2- Parabolic dish reflectors (PDR): The Parabolic Dish Reflector (PDR) uses two axis sun tracking technique to focuses sunlight onto a single point receiver. PTC with two axis

tracking mechanism has the highest potential with 94% of captured solar energy and 32% electrical efficiency.

3- Heliostat field collector (HFC) or power towers, use an array of flat heliostat mirrors to focus sun rays onto a central receiver. Molten salt is used as receiver because it get the better heat storage capacity.

4- Linear Fresnel reflectors: use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a central tower. The central tower height is increase to optimize the land usage and reduce shadow effects in expense of design cost

These technologies differ with respect to optical design, shape of receiver, nature of the transfer fluid and capability to store heat before it is turned into electricity.
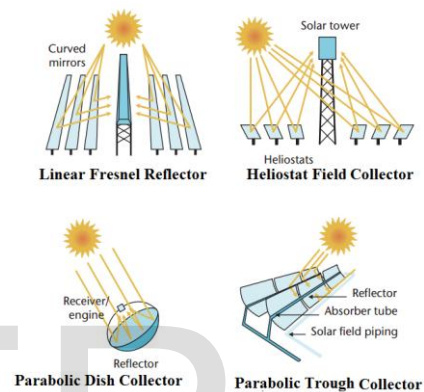

Fig.1 main solar thermal plants technologies

The Sahara Desert extends and covers most of north and west parts of Africa, this include huge parts of Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Western Sahara, Sudan and Tunisia. Utilization of solar potential in Sahara area required installation solar-thermal units in proper locations and further connect them with the DC network pool. The connection of solar-thermal units into common dc network brings a new dimension to the sustainable power economy by pooling the extra generation or the shortfall in the renewable power with the interconnected system.

Morocco has launched one of the biggest solar-thermal power projects in Africa which target generation of 2000MW from solar energy with investment budget estimated by $9 billion by 2020. Five solar power stations are to be installed under supervision of Moroccan Agency for Solar Energy (MASEN). The first plant will be commissioned in 2014, and the entire project in 2019. Once completed, the solar project will provide 18% of Morocco's annual electricity generation.

Tunisia has good solar energy potential of 1,800MW which is until now yet to be harnessed. The solar radiation potential, which ranges from 1800 kWh/m² per year in the North to 2600kWh/m² per year in the South which support large solar-thermal generation plants. The TuNur CSP giant project consists of 2250MW of solar-thermal power generation in Sahara desert. The generated power will be transmitted to Italy and then to rest of Europe. Mali was one of the first countries in Africa to plan for solar generation. Solar irradiation is distrib-

uted over the territory and at 5-7 kWh/m2/day, while there's plenty of space to make use of this irradiation. Projects for building of solar thermal plants with a capacity of more than 100 MW are being prepared but unfortunately the country suffers from political instability and economical problems. The installed capacity of solar thermal power in Africa is summarized in table.2.

Table.2: Installed solar thermal plants in Africa

KaXu Solar One (South Africa)	Parabolic Trough	100MW
Hassi R'Mel (Algeria)	Parabolic Trough	25MW from solar + 130MW from gas plant
Kuraymat Plant (Egypt)	Parabolic Trough	20MW from solar + 120MW from gas plant
Ain Bni Mathar (Morocco)	Parabolic Trough	20MW from solar + 452MW from gas plant

3 THE LAY-OUT OF SAHARA DC NETWORK

The interconnection of different regional network using common dc network is getting wide attention recently. This interconnection increases system stability between different networks and enable then to accommodate the power using power electronic converters to inject/withdraw the power according to specific schedule. Fig. 2 shows a dc interconnected network comprising of four terminals modelled with neutral-point clamped (NPC) converters, and controlled using sinusoidal pulse width modulation. Converter VSC_1 is connected to AC network with wind generation. Converter VSC_2 is connected to AC network with fossil generation. Converter VSC_3 is connected to AC network with solar generation. Converter VSC_4 is connected to AC network with BESS system. It is essential in DC regional network to choose slack bus converter for balancing the power between AC and DC sides and regulate the dc voltage at dc side. The remaining converters are used to control active power injected or withdrawal from the dc pool.
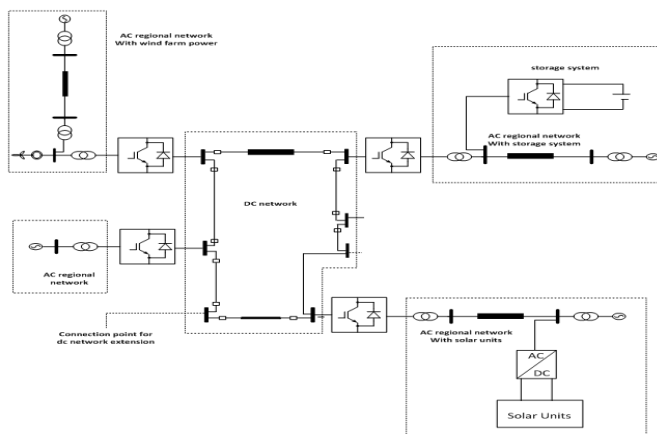

Fig 2 Sahara dc interconnected network

The battery storage system must install in slack bus system to stabilize the power balance in DC pool network. There is central control room for power scheduling between different areas and local control for other purpose controllers. There are connection points in the dc pool to expend the network by providing access for additional AC network.

4 CONTROL OF THE DC INTERCONNECTED SYSTEM

All the VSC converters in the proposed dc network system control the active power flow from/into the dc network except one converter which is used to control the dc network voltage. In this case the converter control the dc link voltages are considered as the slack bus, which achieves the power balancing in the system. The system connected to the slack bus which acts as the power balancer must have a high reserve power generation and high storage capacity. The power-flow in the slack bus is calculated based on the energy balancing law as follows [14]:

$$P_{slack} - P_1 - P_2 - P_{WF} - P_{losses} = 0 \tag{1}$$

The power flow in the dc link cables inside the dc network is determined by the voltage difference between the dc voltages at the converters. The dc voltages at the VSC converters are different according to the amount and direction of the power. The dc voltage is higher when the converters injects power into the dc network and lower when the converter absorbs power from the dc network. The VSC converters dc currents are calculated as follows [15]:

$$I_{dci} = \sum_{\substack{j=1 \\ j \neq i}}^{n} \frac{\left(V_{dci} - V_{dcj}\right)}{R_{dcij}} \tag{2}$$

A central control system is used to coordinate the power injection/absorption for the VSCs and to set the power references for the VSC converters. The DC voltage and the ac voltage control are adopted for the local control in each converter station. Fast and reliable communications to transmit the signals between the converter stations and the central control are required. The power flow re-schedule is achieved by managing the power references in the master control. It is most important that all converter stations have the same ramping speed to avoid unwanted dynamic response. The BESS located in system connected to the slack bus uses AC network frequency as a control signal to respond to frequency variation. Using this signal the references are supplied to the inner controller using additional outer loops designed as follow [16]:

$$i_{sd}^{*} = k_{pf}(f^{*} - f) + k_{if}\int(f^{*} - f)dt \tag{3}$$

Where k_{pf} and k_{if} are frequency controller gains. Fig. 2 summarizes the control system of the battery energy storage systems used in this paper.

5 SIMULATION RESULTS

To study the operation of the dc network proposed for Sahara network four regional are connected together with common dc network with additional open access for other regional network in the future. The network connected to converter 3 is act as the slack bus system which is equipped with BESS to achieve the power balancing in interconnected system. The other systems connected to remaining converters are system injecting or withdraw the power from the common dc pooling.

The power control flow is scheduled in the central control room according to the load variation during the year. The pre-setting of the active power controller for converter1, converter2 and converter4 which inject and draw active power to/from the dc network in time interval between 0-8s are shown in table 3. The negative sign indicate that the converter draw the power from dc network while the positive sign mean the converter inject the power into dc network.

The simulation results obtained during simulation process are shown in Fig. 3 to Figs. 6 showing the active and reactive power exchange of converter stations e with dc network.

In Fig.3 the illustrated waveforms explain the active power injected into DC network by regional network1 according to power schedule planed by the operators in the central control room. The injected power is 400MW at beginning which became 300MW after t=2s and 20MW after t=4s and 100MW after t=6s. Also Fig.4 shows the obtained result for power injection to DC pool by regional network2. The planed injection is 300MW until t=2s, 200MW until t=4, no injection or drawing of power until t=6 and -20MW until t=8s.

Similarly, Fig.5 shows the obtained result for power draw from the DC pool by regional network4. The regional network4 draw 300MW, 200MW, 300MW and 200MW as planed injection is 300MW until t=2s, 200MW until t=4, no injection or drawing of power until t=6 and -20MW until by power operators.

As expected the converter terminal of slack converter VSC3 connected to regional network3 acts as slack-bus for the whole system, to maintain an active power balance between the ac and dc sides taking dc cable losses in consideration as indicated in equation (1). Fig.6 illustrates the power profile exchange with DC network and regional network3 in order to balance the power between the AC and DC sides.

Table3.

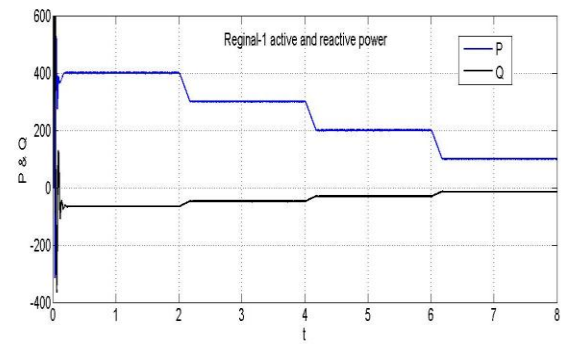| time	VSC1	VSC2	VSC4
0≤ t ≤ 2	400	300	-300
2≤ t ≤ 4	300	200	-200
4≤ t ≤ 6	200	0	-300
6≤ t ≤ 8	100	-100	-200

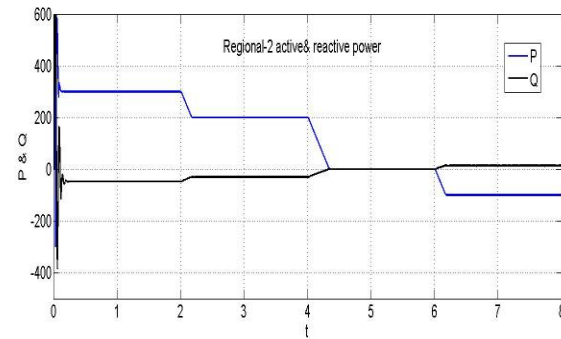Fig.3 network1 active and reactive power at B1

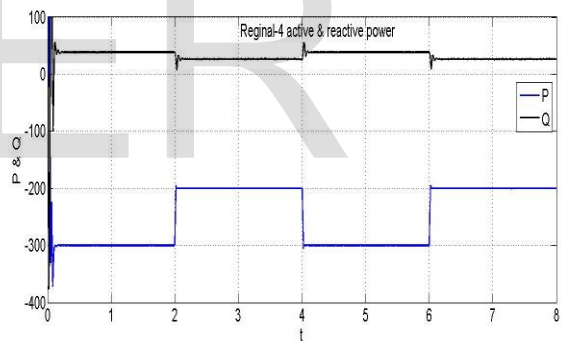Fig.4 network2 active and reactive power at B2
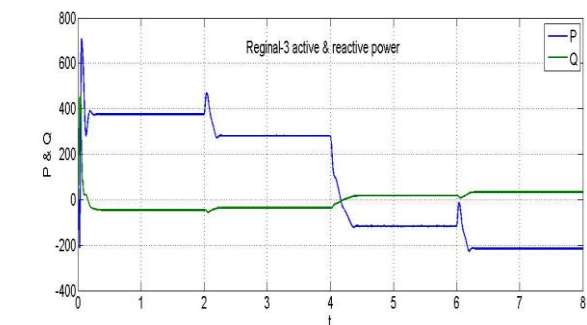

Fig.5 network4 active and reactive power at B4

Fig.6 network3 active and reactive power at B3

The simulation results showed in Fig. 7 to Figs. 10 shows the power exchange in dc cable construction the dc network. The

power flow in these cables depends in converters dc voltages and cable resistances as shown in below:

$$P_{dci} = \frac{\left(V_{dci} - V_{dcj}\right)}{R_{dcij}} I_{dci} \tag{4}$$

Fig.7 shows the power exchange between the converter1 and converter2 in the DC side in response to the power exchange between the regional networks and the DC common pool. As seen the power flow is change as result in changing in power injection schedule. The situation is Similar for power exchange between VSC1 and VSC3, power exchange between VSC2 and VSC3 and power exchange between VSC3 and VSC4 shown in Fig.8 to Fig.10.

Figs. 11 shows that during variations of the active power exchange between dc pool and ac networks, the converter stations are able to maintain constant voltage magnitudes at the points of common coupling using appropriate reactive power exchange with the ac sides.

The results indicate the ability of DC networks in transmitting power from different regional ac networks. In practical, this may help in connecting renewable network which is varies continuously. The variation in renewable network output is balanced using slack bus converter which is connected to strong network.
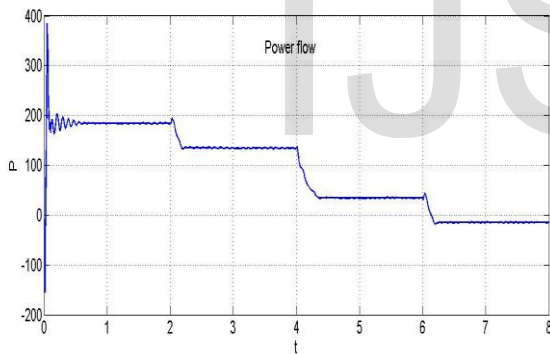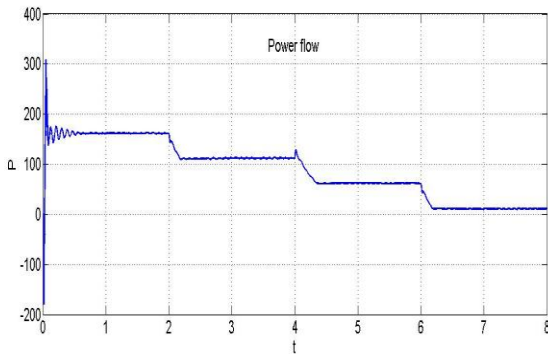

Fig.9 active power flow between VSC2 and VSC3

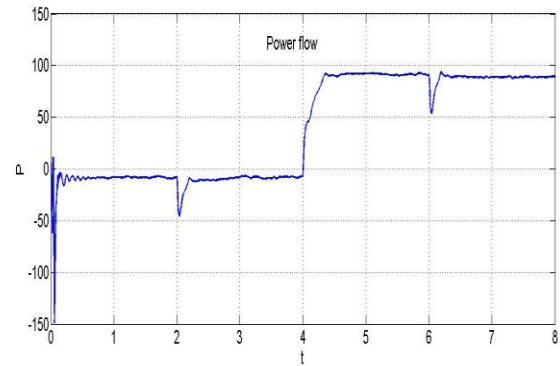Fig.10 active power flow between VSC4and VSC3

Fig.7 active power flow between VSC1 and VSC2

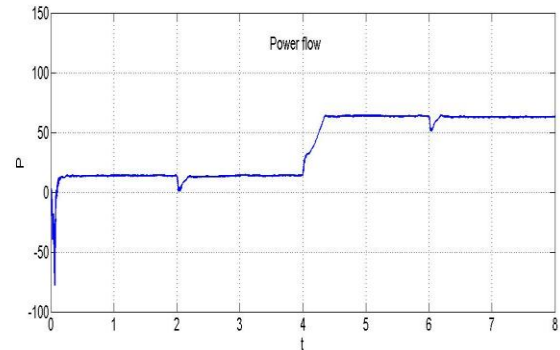
Fig.11: Buses Voltages

Fig.8 active power flow between VSC1 and VSC3
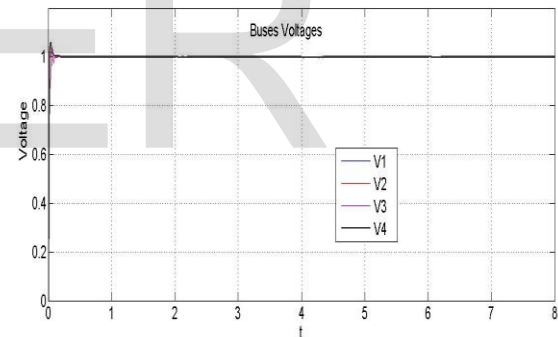
6 CHALLENGING AND OBSTACLES

The main challenging facing the operation of the dc interconnected Sahara network can be summarize as follow:

6.1 Political situation

The political situation in Africa is the major obstacle facing the project. The recent revaluations in Egypt, Libya, Tunisia and the political problems in Mali are driving the developed countries and international organizations for supporting the project.

6.2 Finical and technical support

The construction of Sahara dc network will help in reduction of climate emission and provide the energy for remote areas

in Africa not only this but also the energy could be exported across Mediterranean to Europe. The project initial cost is very high and this required finical support from the developed countries and international organizations.

Also the technical support is required regarding the technologies and skilled experts in the related fields. The example of Siemens helps Egyptian government to install 2GW of wind power is example of the technical support.

6.3 Dc protection system

The protection system of the dc network is a major problem especially during a fault in the dc network. The power converter system copes well with ac faults with appropriate control and protection methods, but it is vulnerable to faults occurring in the DC link and this has limited its practical application dc networks during the last decade. The technology gap in isolation mechanisms of the dc fault and the absence of reliable dc breakers is a real problem facing multi-terminal dc operation. When a short circuit occurs between the dc links conductors, the capacitors rapidly discharge into the fault point circulating excessive dc fault current and as we know Power electronics converters are very sensitive to the overload current and cannot withstand the excessive fault current. With the absence of the zero crossing point and the excessive fault current no dc circuit breaker has been manufactured to handle the dc link fault [17-18].

Several approaches are introduced to address the clearing of the dc fault such as:

1- Using of AC circuit breakers to eliminate the fault in the dc network
2- IGBT circuit breakers placed between each converter terminal capacitors and the dc network buses are used to protect the dc network against the dc network faults.
3- New technology introduced by ABB is capable to address the dc fault issues. In two-switch modular multilevel converter, the current magnitude that converter switches may experience during dc side faults is significantly reduced due to the absence of the dc link capacitors.

6.4 Converter losses

The two standard approaches for the construction DC system are two-level converter or a neutral-point clamped converter and a two-switch modular multilevel converter with medium voltage devices such as 4.5kV IGBTs. Both approaches produce higher conversion losses This required reduction of conversion losses during designing stages [19-20].

6-4 Communication system

Fast reliable communication system is required to transmit the data between the different converter station and the main control central. The Sahara dc network extends to cover the upper part of the Africa and this will required huge and complicated communication system. The power coordination and protection system action depend mainly on these communication system. The data transmitted to local controllers located beside converter station and to central control room located between the converters to achieve the power levelling.

7 CONCLUSION

The idea of building regional network is spread all over the world. The connection of Sahara regional network will help in reinforcement of local networks and facilitate the utilization of solar and renewable potentials available in the area. The revaluation in power electronic technologies regarding power converters helps in connection of AC network with the dc network. The recent scenario suggest DC networking instead of AC coupling which help in isolating the network into small clusters during the sudden disturbance and avoiding complete black-out if problem occur in any network. The central operational control room operate the whole network according to optimal possible injection and withdraw in the network. The local control respond to the voltage support at the common coupling points.

REFERENCES

[1] Viral, Rajkumar, and D. K. Khatod. "Optimal planning of distributed generation systems in distribution system: A review." Renewable and Sustainable Energy Reviews 16.7 (2012): 5146-5165.

[2] Sansawatt, Thipnatee, Luis F. Ochoa, and Gareth P. Harrison. "Smart decentralized control of DG for voltage and thermal constraint management." *Power Systems, IEEE Transactions on* 27.3 (2012): 1637-1645.

[3] Hsieh, Yi-Ping, et al. "Novel high step-up DC–DC converter for ditributed generation system." *Industrial Electronics, IEEE Transactions on* 60.4 (2013): 1473-1482.

[4] D. V. Hertem and M. Ghandhari. "Multi-terminal VSC HVDC for the European supergrid: Obstacles", Renewable and Sustainable Energy Reviews, volume 14, pp. 2010, pages: 3156-31

[5] G. T. Heydt, "The Next Generation of Power Distribution Systems," *Smart Grid, IEEE Transactions on,* vol. 1, pp. 225-235, 2010.

[6] A. Molderink, Bakker, M.G.C. Bosman, J.L. Hurink, and G.J.M. Smit, "Management and Control of Domestic Smart Grid Technology," Smart Grid, IEEE Transactions on, vol. 1, pp. 109-119, 2010.

[7] Z. Ruihua, D. Yumei and L. Yuhong, "New challenges to power system planning and operation of smart grid development in China," in Power System Technology(POWERCON), 2010 International Conference on, 2010, pp. 1-8.

[8] Qu, Liyan, and Wei Qiao. "Constant power control of DFIG wind turbines with supercapacitor energy storage." *Industry Applications, IEEE Transactions on* 47.1 (2011): 359-367.

[9] Hasan, Nor Shahida, et al. "Review of storage schemes for wind energy systems." *Renewable and Sustainable Energy Reviews* 21 (2013): 237-247.

[10] Beltran, Hector, et al. "Evaluation of storage energy requirements for constant production in PV power plants." *Industrial Electronics, IEEE Transactions on* 60.3 (2013): 1225-1234.

[11] Hill, Cody A., et al. "Battery energy storage for enabling integration of distributed solar power generation." *Smart Grid, IEEE Transactions on* 3.2 (2012): 850-857.

[12] Desai, Nishith B., Shireesh B. Kedare, and Santanu Bandyopadhyay. "Optimization of design radiation for concentrating solar thermal power plants without storage." *Solar Energy* 107 (2014): 98-112.

[13] Powell, Kody M., and Thomas F. Edgar. "Modeling and control of a solar thermal power plant with thermal energy storage." *Chemical Engineering Science* 71 (2012): 138-145.

[16] Kalcon, Abdelaziz Y. M. Abbas ", "Multi-task Control for VSC-

HVDC Power Management and Frequency Control", International Journal of Electrical Power and Energy Systems, Volume 53, Dec 2013, pp 684-690.

[16] O. A. Kalcon, G. P. Adam, O. Anaya-Lara, K. L. Lo, and K. Uhlen, "Small-Signal Stability Analysis of Multi-terminal VSC-based DC Transmission Systems," IEEE Transaction on Power System, Volume:27, Issue:4, Page(s):1818-1830, Nov .2012

[17] D. V. Hertem and M. Ghandhari, "Multi-terminal VSC HVDC for the European supergrid: Obstacles " *Renewable and Sustainable Energy Reviews,* vol. Volume 14, pp. 3156–3163, Dec 2010.

[18] S. Gordon, "Supergrid to the rescue," *Power Engineer,* vol. 20, pp. 30-33, 2006.

O. A. Giddani received the B.Eng degree (in honors) in power system and machines from Sudan University of Science and Technology (SUST), Sudan, in 2001, and the M.Sc degree in electrical power system from SUST. He is get the PhD from the University of Strathclyde, Glasgow, UK (2011), his research interest include wind power integration and HVDC system.

Abdelaziz Yousif Mohamed Abbas received the B. Tech. (First class Hons) and M.Sc. degrees from the Sudan University of Science and Technology, Khartoum, Sudan, in 1996 and 2002, respectively, and the Ph.D. degree from Strathclyde University, Glasgow, U.K., in 2009, all in electrical and electronic engineering. From 1996 to 2005, he was a Teaching Assistant then a Lecturer with Sudan University of Science and Technology, where he is currently an Assistant Professor. His research interests include power electronics, drives and energy conversion, power quality and renewable integration, power systems operation and power systems stability and control.

Aamir H. O. Ahmed received the B. Tech. (First class Hons) and the M.Sc degrees in electrical engineering from the Sudan University of Science and Technology, Khartoum, Sudan in 1996 and 2002 respectively. Dr. Aamir obtained PhD degree (2010) in electrical engineering from SUST. From 1997 to 2010, he was a teaching assistant then a lecturer with SUST, where he is currently an assistant professor. He is a head of control engineering department. His research interest includes position/speed control of induction machines and other machines, fuzzy logic control, and sliding mode control. Dr. Aamir supervised many undergraduates and postgraduates students.

Nagm Eldeen Abdo Mustafa Hassanain   received the B.Sc. degree (First class Honors) and M.Sc. degrees from the Sudan University of Science and Technology, Khartoum, Sudan, in 1998 and 2002, respectively in electrical power and machine, and the Ph.D. degree from Strathclyde University, Glasgow, U.K., in 2009, in electrical and electronic engineering. He was a Teaching Assistant from 1998 to 2002, then a Lecturer with Sudan University of Science and Technology, where he is currently an Assistant Professor. His research interests include electrical machine design, electrical machines drives and energy conversion, renewable energy