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Challenges with the Implementation of Distributed Generation in Emerging Markets

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ABSTRACT

Distributed generation (DG) has witnessed rapid growth over the years both in developed and developing countries. This rapid increment in the use (implementation) of DG is due to its numerous benefits. Amongst these many benefits is the elimination of the costs and losses associated with transmissions lines since DG is directly connected to the distribution network. The connection of DG to the distribution network (which was designed solely for distribution of electricity)_*challenged* the traditional approach to system operation and planning developed over the last centuries. The characteristics and cost of the technology used for implementing the DG, the characteristics of the local distribution network, the existing policies in the country, site availability, etc. all form part of these challenges. This work attempts to identify and broadly classified these challenges into commercial, regulations and technical challenges. It is concluded that for the full benefits of DG to be realised in the modern day distribution network, new commercial and technical arrangements should be developed to make the use of DG more cost effective and there should be a policy (which assigns responsibilities and allow budget for implementing innovative solutions for active network management) that encourages the integration of DG into the network.

Keywords*: Distribution, Electricity, Technology, Generator, Wind, Biomass, Technical, Transmission*

I. INTRODUCTION

A Distributed Generation (DG) has no consensus definition but *can be simply put as any generator connected directly to the distribution network.* DG can be implemented with both traditional and non-traditional generator. The energy resource can be renewable, fossil fuels or waste heat. These technologies include solar photovoltaics, fuel cells, wind turbines, small hydroelectric generator, diesel engines, gas turbines, biomass, energy storage technologies, anaerobic digestion and combined heat and power (CHP) systems. Each of these technologies has its own cost, environmental requirement, site location requirement, energy resource need etc. The characteristics of both the technology employed, and the local distribution network constitute the significant challenges that must be carefully study before connecting DG to the distribution network. The use of DG in the modern electricity industry offers valuable benefits (economic, reliability & security, emission, and power quality) but not without challenges. For the full benefits of Distributed Generation to be realised, the associated

Challenges must first be identified and effective solutions provided. These challenges can be broadly classified as commercial, regulation, and technical challenges.

1. Commercial Challenges:

The commercial challenges associated with the use distributed generation include the cost of the technology for implementation, and cost of operating and maintaining the network. Most DGs are still cost intensive and require high initial cost of investment. Some mostly those run on renewable energy sources are currently supported by government incentives. For DG to sustain, technology must improve to reduce this high initial cost. In other cases like using gas turbine for implementing DG, the cost of land for site construction adds to the commercial challenges most especially in densely populated cities where the distribution networks are located. Land use agreement for the construction of DG is still a big case for the developer or the distribution network operator (DNO). In Lagos Nigeria for example, the cost for securing land for this project depending on the location ranges from several hundreds of millions to billions naira. Another aspect is the cost of connecting DG to the distribution network. This can most times be a high burden to the DG developer or the utility company. Finally, with the entrance of DG to the existing network, the network operator is under obligation to maintain the network and ensure quality and security of electricity supply. This can only be achieved through active management of the network which requires high capital investment. Therefore, [1] in order to support the development of active distribution networks and extract corresponding benefits associated with connecting increased amount of DG, new commercial arrangements need to be developed.

2. Regulatory Challenges:

Regulations for DG implementation are governed country-by-country in Europe and state-by-state in the US, while in some cases a complete lack of regulation leaves individual utilities to determine their own standards [2]. Where there are no adequate regulatory standards for DG implementation, the network operator and the potential DG developer usually determine the best way of installing the DG to the network. The cost for this investigation and all the cost implications for the active network management with the integration of the DG to the network add up to the total cost of DG implementation mostly to the potential developer as the distribution network operators would usually pass these costs unto the potential DG developer. This can make DG development cost unattractive and constitutes a drawback to the implementation of DG. The development of standard commercial and technical regulations will further promote DG development. Developments of technical standards are underway. Countries and international bodies are now developing technical standards that will guide the implementation of DG in a cost effective way. In UK, there is now budget for the distribution network operator to be innovative; trialling new technologies and commercial arrangements to better prepare for active network management with the entrance of DG to the network. The solutions will help form standards for DG implementation. On the international level, efforts are being made to provide effective ways of implementing DG. Such effort can be found in the released IEEE standards 1547 and 1547.4. The eventual ratification of standards being developed may greatly increase the cost-effectiveness of DG opportunities [2].

3. Technical Challenges:

The power system engineer faces new technical challenges with the implementation of DG. These technical issues comprise both the technical issues arising from the characteristics of the type of technology employed in the implementation of DG, and the technical issues arising from the entrance of the DG to the distribution network. The characteristics of the type of technology used for implementing DG forms part of the technical issues that must be carefully considered when implementing DG. In general term, the distributed generation can be either inverter based or rotating machine distributed generation. The issues with the inverter based DG is usually with the type of inverter used; the old types of inverters which make use of Silicon Controlled -Rectifier (SCR) produce high levels of harmonics currents. These issues can be solved if the power systems engineer quickly identify the inverter and use the newer types of inverters which make use of Insulated Gate Bipolar Transistor (IGBT) technology to connect the DG to the network. These types of inverters make use of pulse width modulation to generate the injected "pure" sinusoidal wave, producing a clean output with fewer harmonics currents. On the hand, the rotating machine type of distributed generation are not without technical issues that must be carefully analysed. Rotating machines such as synchronous generators constitutes another harmonic source. The harmonics produced by rotating machines depends on the design of the generator windings (pitch of the coils), non-linearity of the coil, grounding and other factors that may result in significant harmonics propagation [3]. In addition to the challenges with the type of technology used, the network planning engineer faces a lot of technical issues when connecting DG to the already existing network which was not planned to handle DG(s). The entrance of DG into the distribution network affects the operation of the network, the quality of power supply and consequently affects the security of the network or reliability of power supply. Many previous research works have been done to discover the impacts of DG on the distribution network by other authors and professional bodies. An attempt is made in this work to identify most significant technical challenges encountered when integrating DG to the distribution network. Some of the major technical issues encountered when connecting DG to the distribution network include reverse power flow, thermal constraint, protection issues, fault levels, voltage levels, and effect of DG on the harmonics of the network. These challenges arise from the alteration of the tradition network paradigm by the connected DG. The traditional distribution network is designed to allow the flow of power from high voltage down to consumers at appropriate low voltages. When a DG is connected to the network, the DG injects power into the network which flow from the customer side to the upstream of the network. The reverse power flow introduced by the DG gave birth to safety issues, network security and power quality within the network. This poses a lot of technical challenges in connecting DG to the distribution network, and subsequent operation of the network by the network operator. *Another technical issues which the electrical power systems engineer faces with the integration of DG into the distribution network is islanding*. Islanding usually take place when one of the protection devices (such as breaker, fuse etc.) in the network trips upstream from one or more generators leaving the generator(s) to energise a certain part of the network that is separated from the utility network by the tripped device to form an isolated power island with the DG(s) as the only power source. Islanding [3] occurs when the distributed generator (or group of DGs) continues to energize a portion of the utility system that has been separated from the main utility system. The concept of islanding on a grid system is unique insofar as it is regarded as a dangerous problem to be avoided in some cases, but regarded as a benefit to the system performance in other cases [4]. To further discuss each of these technical challenges and to fully appreciate them, the distribution network and the technical challenges with the implementation of DG are briefly discussed below.

4. Distribution Network and Technical Challenges with implementation of DG:

Distribution network is the final electricity network that delivers electricity to the customer. It is the network of wires/cables between the transmission network (high voltage that carry bulk of power from the generating stations) and the consumers' homes. The distribution network takes electricity from the transmission network at high voltage level and through series of voltage transformation process, delivers the electricity to the consumers at the appropriate voltage levels. In UK, electricity is usually deliver between 132KV (EHV distribution), 33KV & 11KV (HV distribution) and 400/230V (LV distribution). Nigeria operates a similar system but 415/240V LV distribution.

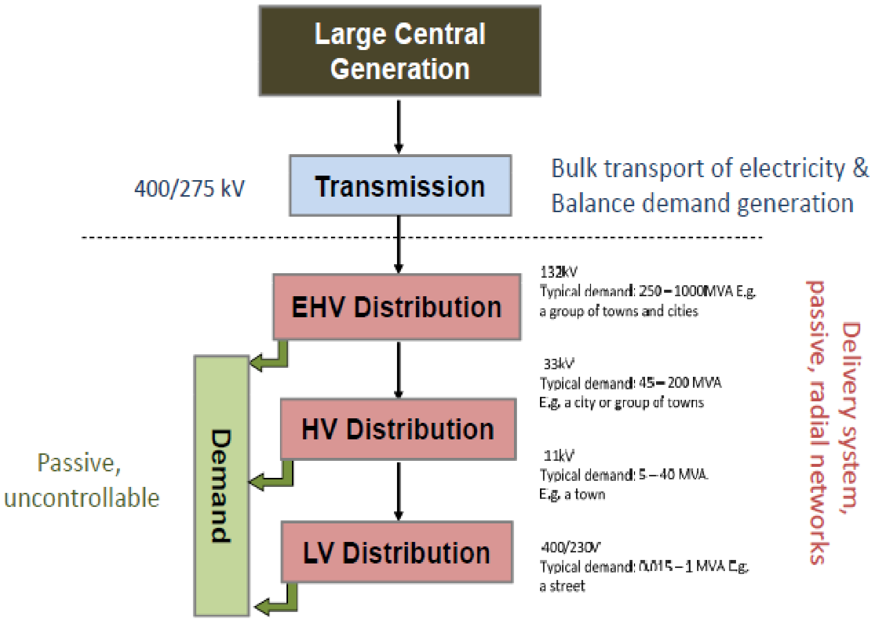

Fig.1: Structure of the Electricity System

The traditional distribution network is a passive, *radial network* designed to take power from high voltage to low voltage allowing power to flow in one direction along the radial feeders. Regardless of the over-arching style of the grid network, distribution systems throughout the world are accomplished primarily in a radial fashion [5].

Fig.2. below illustrates a radial network having two feeders. Each of the feeders is protected by a circuit breaker at the substation and feeds the connected loads downstream independently from the other. The two feeders both take supply from a common bus at the substation. In some cases, the two feeders can be connected together with

a normally open (N.O) switch which is referred to as intertie switch. This increases the reliability of the network as the switch can be closed (hence the feeders are looped together) as when needed such as during fault or maintenance in any part of the network. Contrarily to this, low voltage distribution network can be operated in a meshed style (shown in Fig. 3). In the meshed distribution network, a single low voltage bus that feeds multiple loads connected to it is fed by multiple feeders from the single supply source. This increase reliability of power supply as supply will not be interrupted in case of any out of service of any of the feeder(s). They find application in areas where high levels of supply reliability is needed.

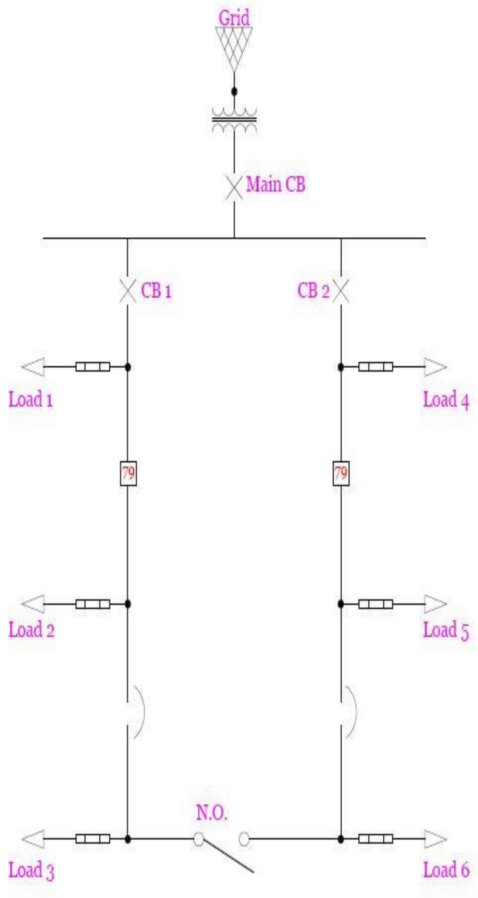

Fig. 2: Radial Distribution Network

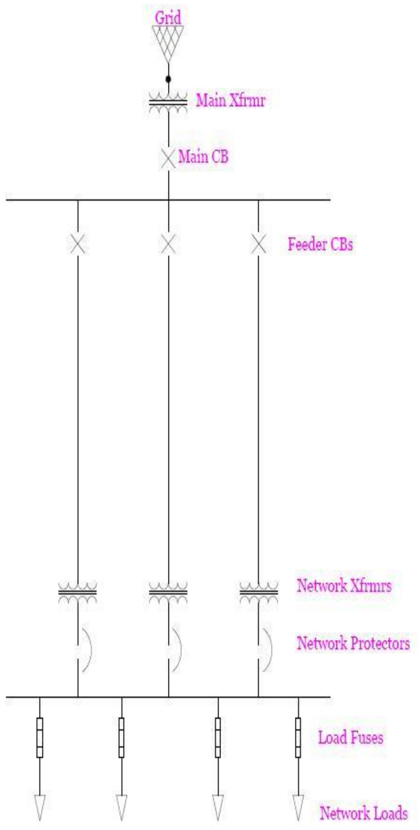

Fig. 3: Meshed Distribution Network

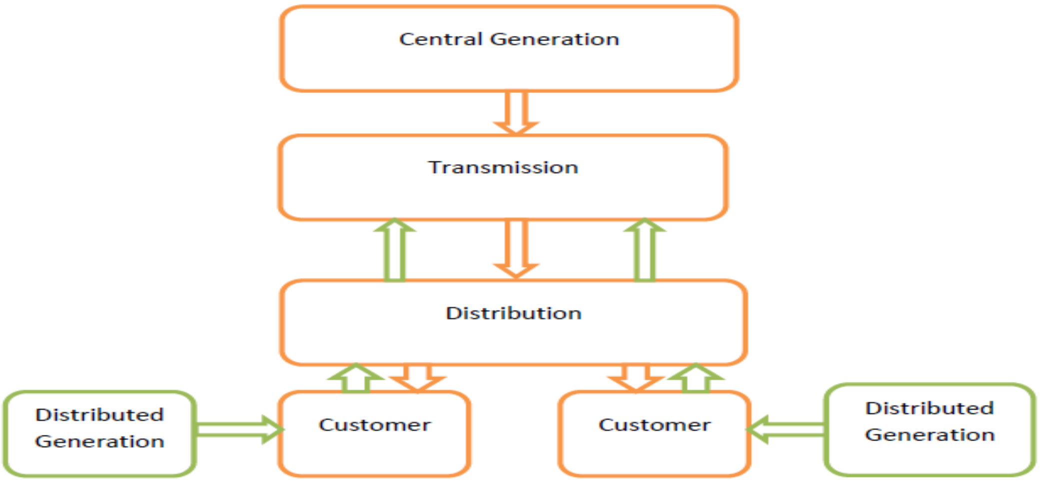

Fig. 4: Modern Electricity Distribution Network with DG

The one way power flow in the passive, uncontrollable distribution network simplifies the operation of the network but with the entrance of a DG into the network (Fig. 4), the network becomes active and changes the radiality of the network. *The loss of radiality of the distribution network is the birth of the technical challenges encountered when accommodating DG(s) into the network*. According to [6], the integration of DG presents new challenges for distribution system planning and operations, principally because the configuration of power lines and protective relaying in most existing distribution systems assumes a unidirectional power flow and are designed and operated on that assumption.

As mentioned before, the most common but serious technical issues encountered with the entrance of DG into the network are reverse power flow, thermal constraint, protection issues, fault levels, voltage levels, effect of DG on the harmonics of the network and islanding.

Reverse Power Flow:

This is the mother of the technical challenges facing the implementation of DG into the distribution network. Simply put, reverse power flow is the flow of power (current) in opposite direction to the original or predefined direction. The traditional distribution network as described above is designed to operate radially allowing a unidirectional power flow from upper terminal voltage levels down to customers situated along the radial feeders. When a DG is connected to the distribution network, the DG changes the radiality of the distribution network. This loss in the radiality of the distribution network causes a reverse power flow, from the customer end to the upstream of the network in opposite to the traditional upstream to downstream customer end as shown in fig.4. This reverse power flow in the network due to the presence of the DG(s) leads to other technical issues in the network. The issue with power flow reversal will be unique in each DG case; the issue must be addressed with regard to the specific generating unit being implemented as well as the specifics of the distribution system it will interconnect with [7].

Thermal Constraint:

This is associated with the current flowing in the network. The network equipment have been originally designed to withstand certain limits of current capacity. When a DG is connected to the network, it injects power onto the network. [8] The generator may supply loads located up and downstream of the generator connection. Equipment close to the distribution station will be less heavily loaded because a portion of the demand is being supplied by the generator; however, equipment close to the generator will be more heavily loaded. If the DG capacity connected to the network exceed the upstream network firm capacity, the network assets will be at risk of operating above their current rating limits resulting in failings of assets and consequently following outage. This places limit to the capacity of DG that can be connected into the network if the equipment must not fail. This condition is referred to as thermal constraint on the network.

Protection Issues:

Protection in the traditional radial distribution network is based on the assumed unidirectional power flow from upper voltage levels down to customers situated along the radial feeders enabling straight forward protection. But when the network loss its radiality due to the entrance of DG, power begins to flow bidirectional and the effectiveness of the network protection equipment is reduced. According to [9], under conditions of current flow in the opposite direction, protection mal-operation or failure may occur with consequent increased risk of widespread failure of supply. Impacts of DG on protection devices include but not limited to blinding of protection, false (sympathetic) tripping, prohibition of (automatic) network reclosing, and islanding.

Isanding:

Islanding usually take place when one of the protection devices (such as breaker, fuse etc.) in the network trips upstream from one or more generators leaving the generator(s) to energise a certain part of the network that is separated from the utility network by the tripped device to form an isolated power island with the DG(s) as the only power source. Islanding has an impact on the safety of both the utility and the connected loads, all customer loads connected to this power island will face fluctuations in both voltage and frequency, and those fluctuations might cause severe damages as the voltage and frequency at their terminals are deviated than the standard required level [10].

Fault Levels:

The connection of DG to the distribution network makes contribution to fault levels. The influence of DG to faults depends on some factors such as generating size of the DG, the distance of the DG from the fault location, and the type of DG [11]. Basically, DG causes increase in fault levels in the distribution network. This increase is caused by an additional fault level from the generator [9]. Thus, the connection of DG to the network could cause distribution network, which happens to be close to its fault level limit, to exceed it. All equipment close to the point of connection may all be affected. Increasing fault currents with the introduction of DG could lead to failure of the protective scheme and consequently causing risk of injury to personnel, and interrupting power supply.

Voltage Levels:

The effects on voltage levels by the DG which can either be positive or negative arises primarily due to reverse power flow introduced into the network by the presence of the DG. Reverse power flows means reverse voltage gradient along radial feeders and this may counteract normal voltage drop across a transformer, resulting in higher voltages on the secondary customer side. The presence of DG will directly affect voltage profiles along a feeder by changing the direction and magnitude of real and reactive power flows. As noted by CIRED questionnaire [12], next to the general impact on power quality, a rise in the voltage level in radial distribution systems is mentioned as one of the main technical connection issues of DG. Voltage profiles along loaded distribution network feeder are typically such that the voltage level is at maximum close to the distribution network transformer busbar, and the voltage drops along the length of the feeder as result of the loads connected to the feeder [9]. DG along a distribution feeder will usually have the effect of reducing the voltage drop along the feeder, and may lead to a voltage rise at some points which could push the feeder voltage above the statutory voltage limit. This effect can be positive in some networks where there are low voltages, as in this case the DG will contribute to the voltage support. But it becomes an additional problem in some networks where contribution to voltage by the DG unit will lead to overvoltage in the network due to too much injection of active and reactive power.

To ensure high quality of power, the voltage levels along the feeders must be regulated to keep them within acceptable limits – usually within 5 -10% of the nominal operating voltage (ANSI is ±5%). This is normally achieved by using load-tap changing transformers (LTC) at substations. In addition, the voltage regulation is also achieved through the control of reactive power flow by using line regulators on distribution feeders and shunt capacitors on feeders or along the line. The standard practice is based on radial (one way) power flow from substation to loads. But the connection of DG introduces 'meshed' power flow into the network as the network losses its radiality and power begins to flow bi-directionally which interferes with the effectiveness of the standard voltage regulation practice.

The integration of DG into the existing radial networks can therefore complicate the regulation of voltage across the length of distribution feeders. Although some DGs (which consume and/or supply reactive power) can also play a role in voltage regulation in the network, [6] IEEE standard 1547 forbids DG units from actively regulating the voltage at their interconnection point.

Harmonics*:*

A wave which does not follow a pure sinusoidal waveform is said to be harmonically distorted. There is no ideal electricity network where the voltage follows a perfectly sinusoidal waveform oscillating at the desired fundamental frequency. Harmonics are always present on utility systems to some (manageable) extent. Non-linearity in transformer exciting impedance or loads (e.g. fluorescent lights), rectified DC power supplies, arc furnaces, variable speed motor drives, switch-mode power equipment, welders, and other equipment, usually introduce or amplify 'harmonic' components into the voltage sine wave, thus distorting the voltage waveform. DG can form additional source of harmonics to network, [13] in some cases, increase harmonics on the network from acceptable to objectionable levels.

The harmonics contribution from the DG can either be from the generator itself or from the power equipment such as inverters used in converting the generated DC to AC to be injected to the network. Therefore, the type of generator and the power equipment should be considered when connecting DG to the network.

II. CONCLUSION

The challenges with the implementation of DG in the modern day distribution network has identified in this work must be diligently eliminated before the full benefits of DG can be realised. New commercial arrangements should be developed to make the use of DG more cost effective. The development of standard commercial and technical regulations, trialling new technologies and commercial arrangements to better prepare for active network management with the entrance of DG to the network will encourage the use of DG. There should be a policy that encourages the integration of DG into the network. The policy should provide for the use of innovative solutions in network planning and operation. The policy should assign responsibilities and allow budget for implementing innovative solutions for active network management.

REFERENCES

[1] J.A. Pecas Lopes a, N. Hatziargyriou, J. Mutale, P. Djapic c, N. Jenkins, "Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities". Electric Power Systems Research 77 (2007) 1189–1203. 2006. [Online]. Available: http://www.eee.manchester.ac.uk/research/groups/eeps/docs/mutale_2007A.pdf

[2] Golkar, M. (2009). "Distributed generation and competition in electric distribution market". *Ieee Eurocon 2009, Eurocon 2009,*

[3] Philip P. Barker, R. W. (2000). Determining the Impact of Distributed Generation on Power Systems: Part 1 - Radial Distribution Systems. 12. IEEE. Retrieved 02 16, 2011, from IEEE.

[4] Scott G. M. Therien, "Distributed Generation: Issues Concerning A Changing Power Grid Paradigm", Master Thesis, the Faculty of California Polytechnic State University, San Luis Obispo, 2010.

[5] Power Quality Impacts of Distributed Generation. EPRI, Palo Alto, CA 1008507

[6] Future of the Electric Grid, An Interdisciplinary MIT Study, Massachusetts Institute of Technology, 2011. [Online]. Available: http://web.mit.edu/mitei/research/studies/documents/electric-grid- 2011/Electric_Grid_Full_Report.pdf

[7] Chowdhury, S.P., Chowdhury, S., & Crossley, P. (2009). "Islanding protection of active distribution networks with renewable distributed generators: A comprehensive survey". *Electric Power Systems Research*, *79*(6), 984-992.

[8] Madeleine Schaefer, Engineering Challenges With Distributed Generation, University of British Columbia, 2012, [Online]. Available: https://circle.ubc.ca/bitstream/handle/2429/42199/Schaefer_Madeleine_2012_EECE492_Final_Report.pdf?sequence=1

[9] Loi Lei Lai and Tze Fun Chan, Distributed Generation: Induction and Permanent Magnet Generators, John Wiley & Sons, Ltd, 2007, pp. 1-29.

[10] M. A. Redfern, and O. Usta, "A new microprocessor based islanding protection algorithm for dispersed storage and generation units", IEEE Transaction on Power Delivery, vol.10, pp. 1249-1254, July 1995.

[11] Angel Fernández Sarabia, "Impact of distributed generation on distribution system", Master Dissertation, Department of Energy Technology, Aalborg University, Aalborg, Denmark, June 2011.

[12] CIRED, 1999: Dispersed generation, Preliminary report of CIRED working group WG04, June, p. 9+Appendix (p.30).

[13] Umar Naseem Khan, "Impact of Distributed Generation on Electrical Power Network", Wroclav, University of Technology, Poland.