DC- Versus AC Minigrids for Sub-Saharan Africa

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Ulster University

Dr. Nicholas N. Opiyo

n.opiyo@ulster.ac.uk

Introduction:

A Minigrid is defined as a locally confined and independently controlled electric power grid in which a distribution architecture integrates distributed loads and distributed energy resources

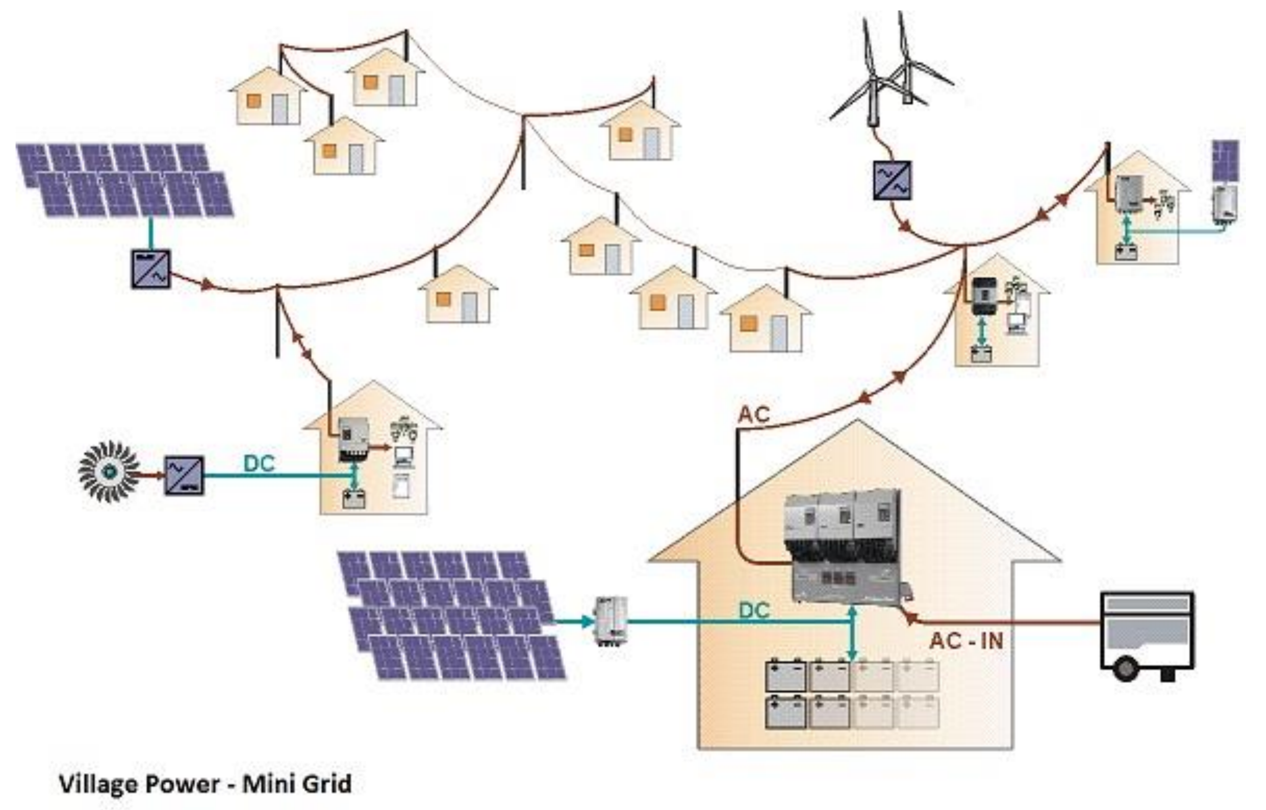

Fig. 1: A PV-Based Hybrid Minigrid

Power losses in minigrids are mainly due to cable losses, voltage (IR) drops, and rectifier (conversion) power losses. In DC systems, these can be modelled as [1]:

$$\Delta P_{DC} = 2.R.\frac{P^2}{V_{DC}^2} \qquad (1)$$

Where *P* is the transmitted power, *R* is the resistance per core, and *VDC* is the voltage level.

In single-phase AC systems, power losses are modelled as [1]:
Where $\emptyset$ is the phase angle.

$$\Delta P_{1\emptyset} = 2 \cdot R \cdot \frac{P^2}{V_{rms}^2 \cdot cos^2\emptyset} \qquad (2)$$

The ratio of (1) to (2) is given by:

$$\frac{\Delta P_{DC}}{\Delta P_{1\emptyset}} = \frac{V_{rms}^2}{V_{DC}^2} cos^2\emptyset \qquad (3)$$

From (3), we can infer that DC systems perform better than AC systems with guaranteed equal transmitted power for the same load with very low stress on the dielectric.

Methodology:

Four different minigrids of same size are modelled and simulated in MATLAB/Simulink to compare their costs and ease of expansion based on the total; number of conversion stages. The minigrids are classified as: a) DC minigrid with decentralised storage, b) DC minigrid with centralised storage, c) AC minigrid with decentralised storage, and d) AC minigrid with centralised storage. Figure 2 shows a DV copupled minigrid with decentralised storage.

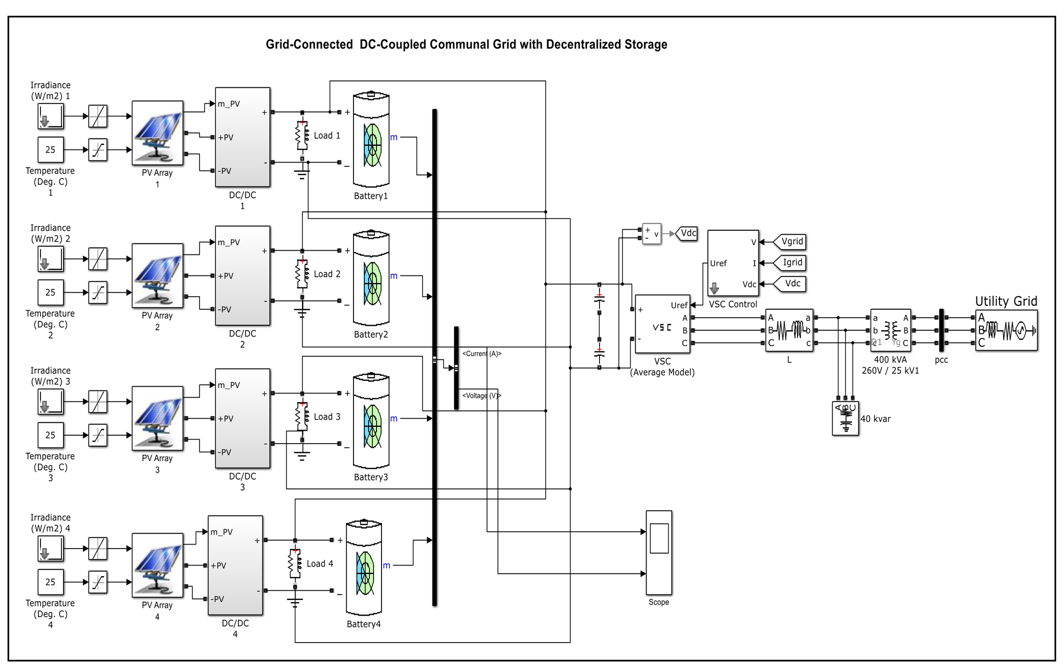

Fig. 2: Simulink Model of a DC-Coupled Minigrid

Results and Discussion:

After 25 years, 2,410 consumers would have joined minigrids with decentralised storage systems, representing 24.6% of all consumers. This is higher than the 2,011 consumers that would have joined networks with centralised storage systems, representing 20.5% of all households.

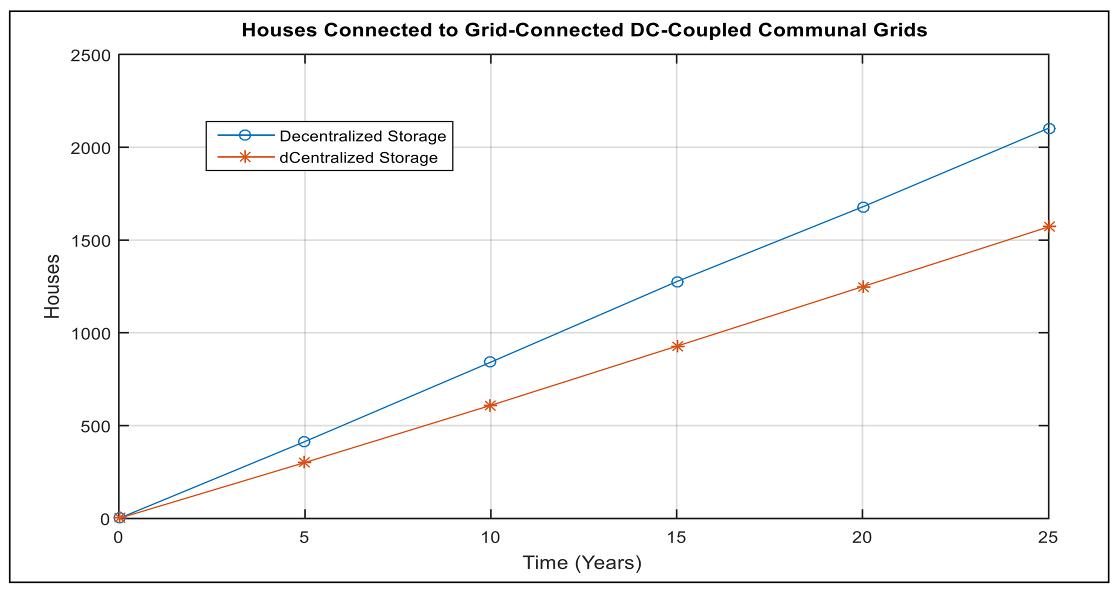

Fig. 3: Consumers Connected to Islanded DC-Coupled Networks

After 25 years, 2,179 consumers would have joined minigrids with decentralised storage systems, representing 22.2% of all consumers. This is higher than the 1,728 consumers that would have joined networks with centralised storage systems, representing 17.6% of all consumers.

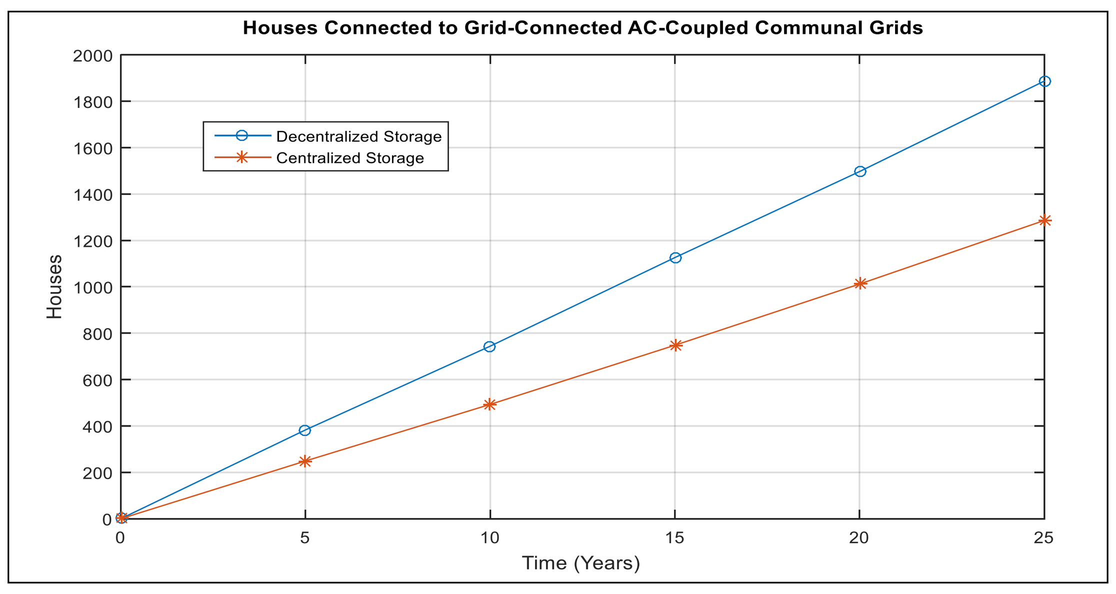

Fig. 4: Houses Connected to AC-Coupled Networks

Conclusion:

Generally, DC-coupled networks seem to fair better than AC-coupled networks in all categories. This is mainly due to cost and ease of set-up of such networks; DC systems are more modular and scalable than AC systems because DC converters are easier to control and to parallel. This allows for more flexibility in system design and expansion, and thus more effective capital investment management. Table 1 summarises the above information.

Table 1: Comparison of Houses Connected to DC- and AC-Coupled Networks

Time (Years)	DC-Coupled		AC-Coupled	
	Decentralised Storage	Centralised Storage	Decentralised Storage	Centralised Storage
0	0	0	0	0
5	507	403	421	322
10	1028	831	854	669
15	1521	1233	1304	1017
20	1982	1627	1756	1365
25	2410	2011	2179	1728

By avoiding many power conversion stages, DC networks supplied by DC power sources such as PV systems are the most cost-effective paths to rural electrification. Efficiencies could be improved further if DC-inherent appliances are used with the DC networks, further eliminating power conversion losses. Results also show that, based on costs, consumers would prefer to join DC minigrids as opposed to AC minigrids due to lower connection fees, ease of grid expansion, and overall better performances.

1. Laudani, G., Mitcheson, P., Comparison of Cost and Efficiency of DC versus AC in Office Buildings, Report for Transformation of the Top and Trail of Energy Networks, Imperial College, London, 2017