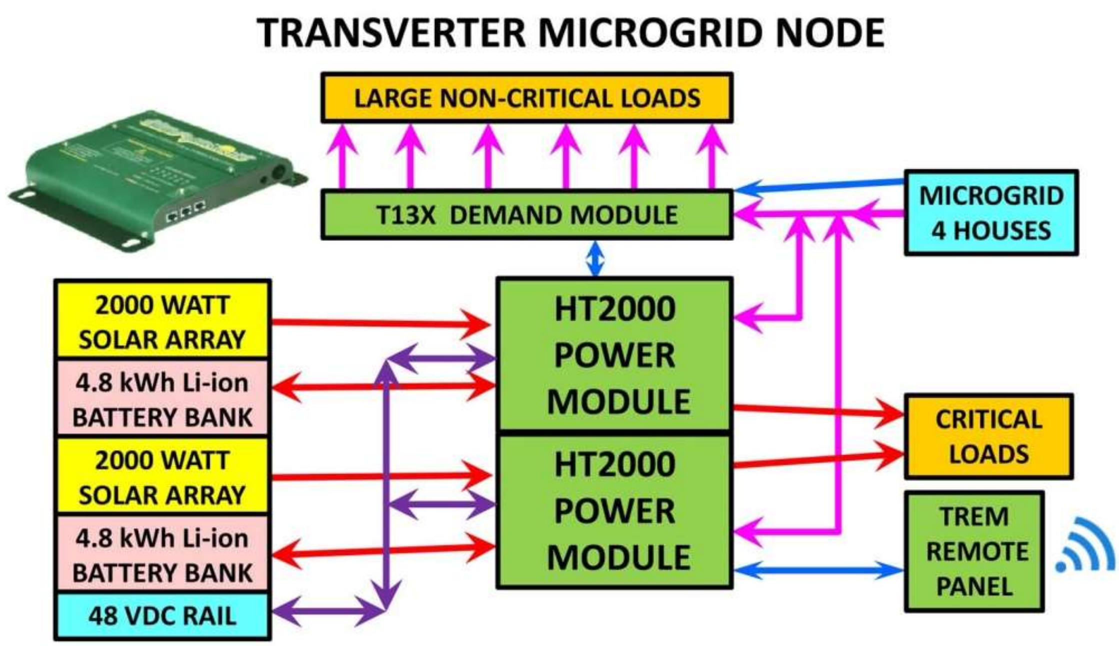
DC Transmission Lines for Microgrids

By Heart Akerson, CEO of Heart Transverter

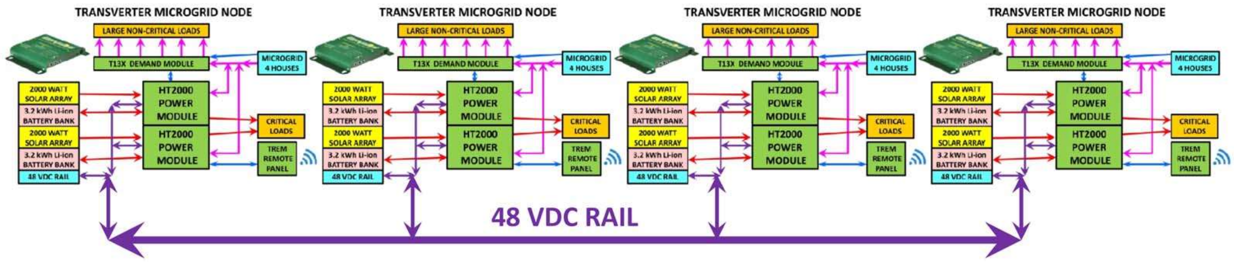
The idea of Microgrids is to have distributed sources of energy spread all over with the ability to break apart and power local loads independently, regardless of what has happened with the rest of the larger system. A well designed Microgrid can also be used to support the larger system while connected through injection of energy at peak times. This gives the highest level of energy security and can significantly reduce the cost of the infrastructure, both capital and operating, because the infrastructure is only balancing resources rather than running most of the energy over long distances. Since we are now moving smaller amounts of energy over shorter distances there are a number of options that enhance performance and lower costs. Just connecting a bunch of products that say Microgrid on them together does not create a workable system. The topology and control need to be carefully planned or the pieces will not fit together and function. This all complies with Puerto Rico's Microgrid standards CEPR-MI-2018-0001 which can be downloaded at:
http://www.pridco.com/real-estate/Pages/RFP_FY2018-2019-002_Anasco/Regulation_9028-Regulation_on_Microgrid_Development.pdf

Basic Home Microgrid Node. Look at the Transverter Microgrid node for one house or small business.



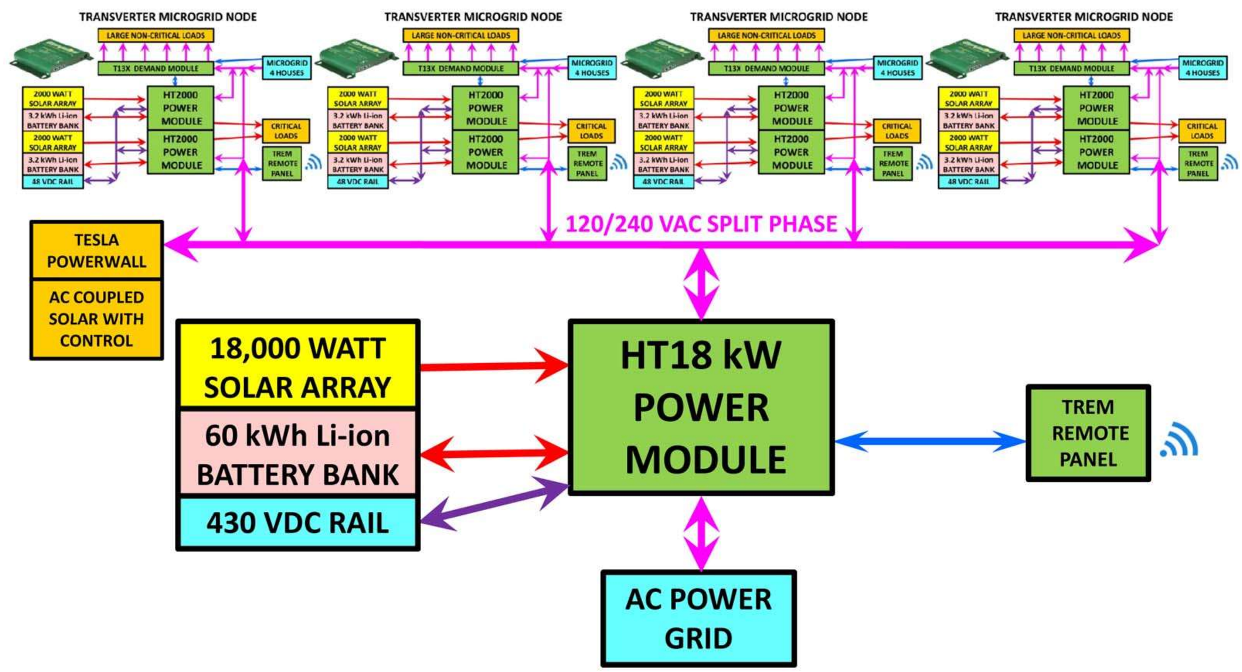
This gives power to critical loads, like lighting, refrigeration and electronics from its own resources but can be interconnected to form a local Microgrid of 4 houses to power larger, non-critical loads, like a clothes dryer.

48 VDC Rail. This system also produces 4 kW of power at 48 VDC which can be used to share energy with other Microgrid nodes that are right next to it. This is commonly done in cell towers, where all of the loads are 48 VDC, or with server racks in data centers.



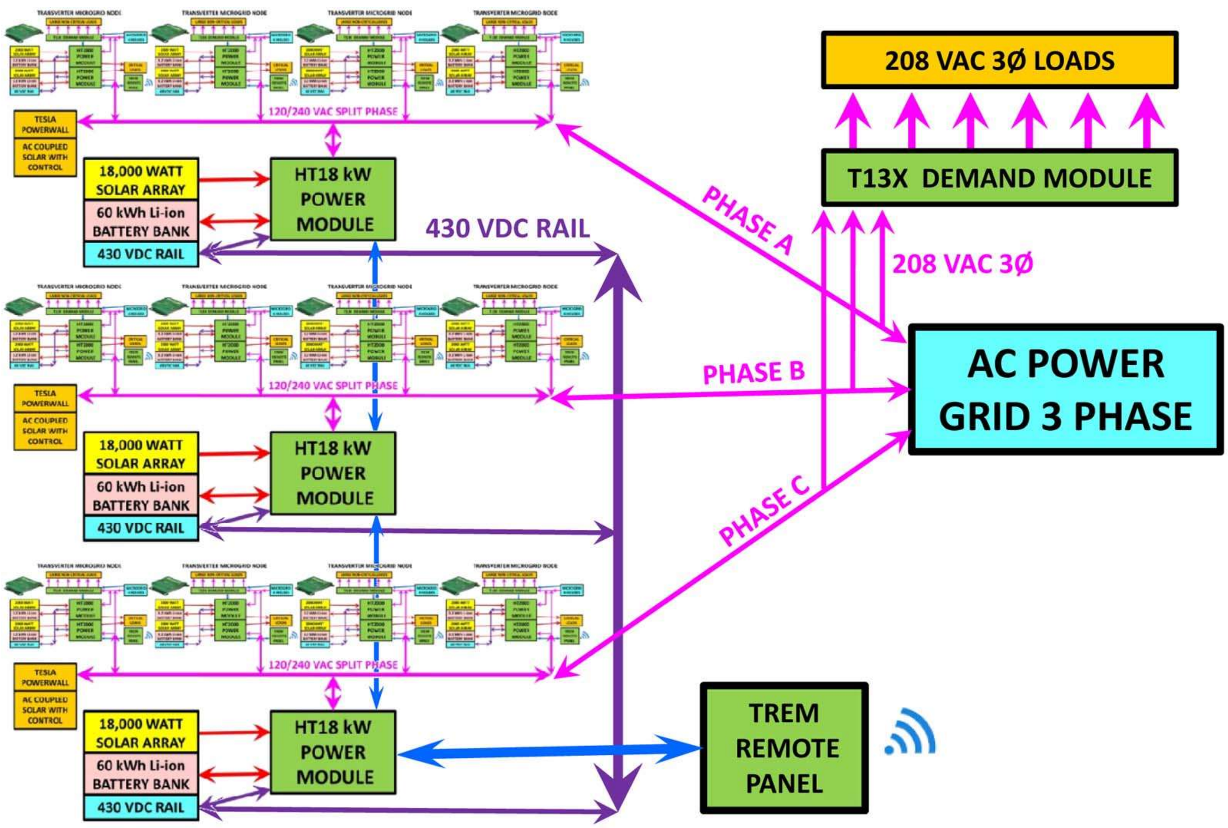
The currents would be too high at 48 VDC to make this practical between houses. For this we use the magenta lines, which are 120/240 VAC split phase like is typical in homes. Actually, the LED lighting and most electronics in the homes could run off 48 VDC. All LED's are DC anyway and need power converters to change the AC to DC so making lights that ran off 48 VDC would make them cheaper to manufacture, more efficient and last longer. The same is true for most electronics. In addition, some people are concerned about electromagnetic radiation from the AC wiring in the house and DC does not create any electromagnetic radiation at all.

Microgrid, next level. Transverter Microgrids lend them self to a tiered structure. The next tier level is to an 18 kW power module with its own solar array and batteries.



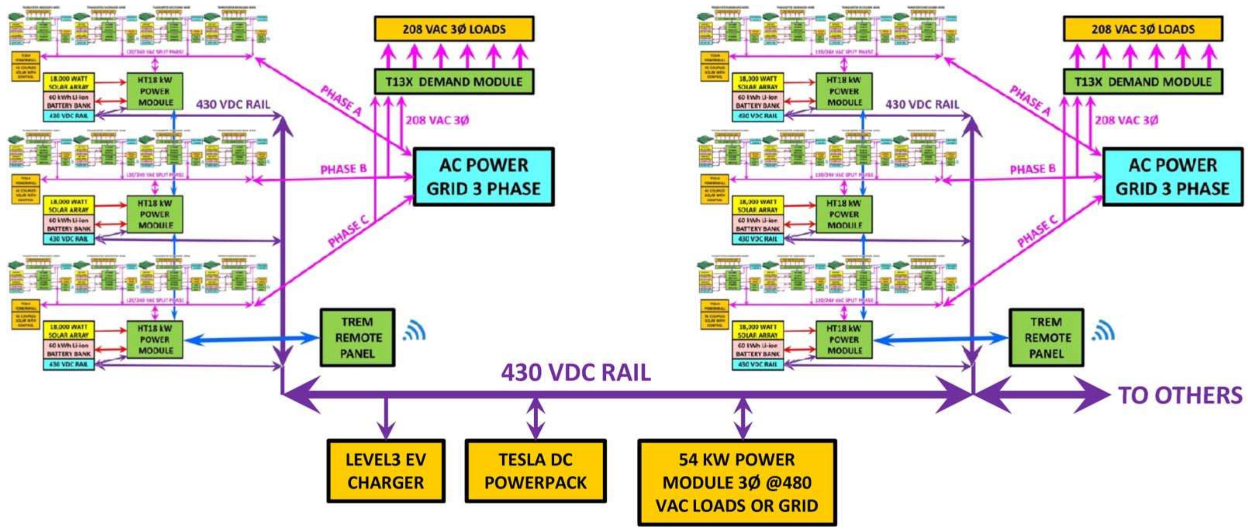
This solar array can be up to 430 volts peak and the batteries are normally 400 VDC like those used in electric vehicles. In fact, it can be an actual EV that is parked there, where the EV is both charged from the system and can provide power to the system. All of the individual home Microgrid nodes automatically synch to the frequency and phase coming from the 18 kW power module. This magenta line allows power to flow in both directions between any components in the entire system. The solar panel on node#1 can actually charge the battery on node#4. The larger non-critical loads now have access to all of the shared power, 4 X 4kW + 18 kW = 34 kW. All of these non-critical loads are run through T13X demand modules which have priority levels set and will automatically be shed when the total loads start to reach the total power capability or energy available of the system. Other 120/240 VAC Microgrid components can connect to this Microgrid, like a Tesla Powerwall or AC coupled solar with control built in. Control is the essential element here, usually through MODBUS, and many devices now have this built in. All of the data for all energy transactions is collected by each node's edge device and the HT18 kW master device so detailed accounting can be done for buying and selling energy, most easily administered through a power purchase agreement (PPA). However, this is like a PPA on steroids where it can have floating TOU rates with automatic responses from all of the non-critical loads. No matter what happens, or what priorities are set, each node (or home) has assurance that they always at least have their own batteries and solar as resources for their own critical loads.

Microgrid for 3 Phase. Now we move up to the next tier where 3 of these systems are connected together for 3 phase connection to the grid with a 430 VDC rail connecting the 3 systems.



Not only can this system connect to a 3 phase grid but it can automatically balance the 3 phases so there is no current flowing through the neutral to the grid, all power factor corrected, which optimizes the grid resources. You can also connect 208 VAC 3 phase loads to the system that will work, even when the grid is down. Some of these 3 phase loads are important like large water pumps and sewage pumps and will be monitored and controlled by a Demand Module. The 430 VDC rail now connects all of the nodes on all 3 systems so that energy can transfer between the solar panel of node#1 on System A and the battery of node#4 of System C. Again, all large non-critical loads are controlled and all energy transaction accounting can be administered by a single PPA. This example now has 12 houses yet there is only one grid connection and meter so things like TOU rates and Demand charges can be administered and optimized.

Multiple Microgrids Sharing. The next level is you could have several of these complete systems separated by reasonable distances and connected by the 430 VDC rail. Under Puerto Rico's Microgrid standards these sharing Microgrids would either have to have the same owner or go through PREPA, Puerto Rico's centralized grid company.



Just as there are loads that can connect directly to the 48 VDC rail there are heavy power items that can connect to the 430 VDC rail, like Level3 EV chargers, Tesla DC Powerpacks @ 200 kWh and 3 phase inverters for 480 VAC 3 phase loads, and bidirectional inverters to connect to the grid at 480 VAC 3Ø.

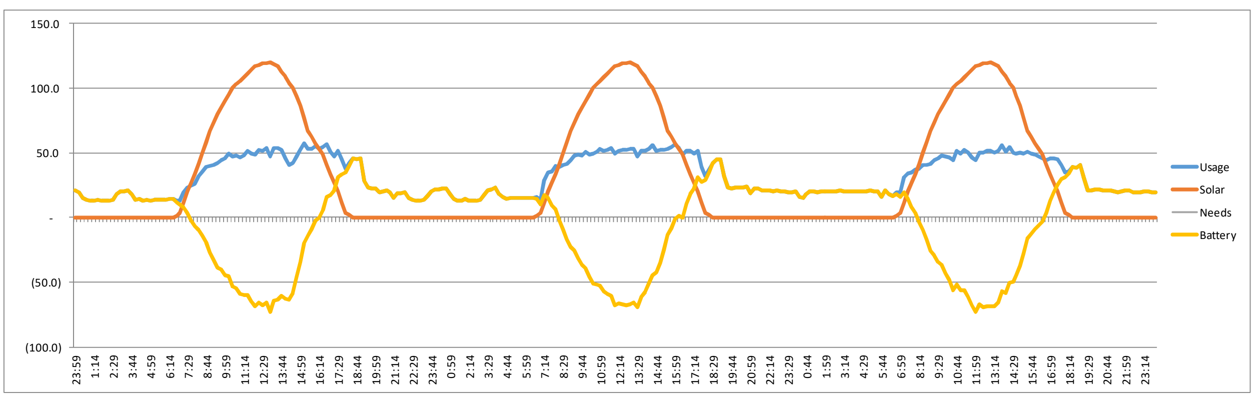
Transmission Lines. So we need something more specific than a "reasonable distance" for these 2 wires carrying 430 VDC. Keep in mind that this is not like a centralized grid where all of the power is going through transmission lines all of the time. All of our nodes have significant power sources and energy storage so we really only have to transfer power over these lines sporadically, just to balance things out, with a lot of time with no transfer of power at all,.

	Wire Size CU	Amps	Power kW	P Loss	# of wires	D feet	Ploss @ 1/2 P
240 VAC 1Ø	6	67.5	16.2	10.0%	3	450	2.50%
430 VDC	6	67.5	29.0	10.0%	2	806	2.50%
208 VAC 3Ø	6	67.5	48.6	10.0%	4	900	2.50%
430 VDC X2	6	67.5	58.1	10.0%	4	806	2.50%

It is common to run wires for 120/240 AC split phase. From this chart you can see that, with #6 copper wire, you could go 450 feet with a 10% power loss at 16.2 kW and a 2.5% power loss at ½ power. This would require 3 wires, one for each line and one for neutral. For 430 VDC you could use only 2 wires of the same #6 gauge and run 806 feet for a 10% power loss at 29 kW and a 2.5% power loss at ½ power. Going to 430 VDC gives you more power and longer distance using only 2, instead of 3, wires.

Our discussions so far have been with 3 phase systems at higher powers. For 208 VAC 3 phase you would need 4 wires and #6 copper would run 900 feet with a 10% loss at 48.6 kW. The 430 VDC system could use the same 4 #6 wires, but double them up since you only need 2, and run 806 feet but at 58.1 kW. You get a little less distance but a higher maximum power of 58.1 kW. You could use #4 aluminum wire with the same results (actually you should decrease the distance by 5% for aluminum). These use really economical, readily available 600 volt rated wire. Go up to #4 copper or #2 aluminum and you could run the 430 VDC double lines for 1,282 feet or run it up to 87.1 kW for 855 feet. 58.1 kW is a lot of power to transfer just to balance out these systems. This DC transmission line would have fewer losses when underground in wet dirt because of the capacitive effect of the dirt. That is why most high power underwater cables are done at high voltage DC. See **High-voltage direct current**. Some people are concerned about the health effects from the electromagnetic radiation emitted from AC power lines and DC lines eliminate this. Notice that the frequency base and phase of each system, with a DC transmission link, are totally independent. They only become synched when both systems connect to the same grid. You could actually have a situation where one system was 50 Hz and the other was 60 Hz and the DC transmission line would work fine. That situation actually exists in Japan and Jamaica. It is easy and economical to run underground electrical wires under 600 volts where it is very expensive to run underground at 20,000 volts which is the normal range for medium voltage lines between the grid substation and the transformer near each house.

Costs. We used an example of 4 houses or nodes per subsystem for a total of 12 nodes. You could easily have 8 nodes per subsystem for a total of 24 nodes, along with the 54 kW 3 phase master system giving a total system with 150 kW of solar, 150 kW maximum load capability and 337 kWh of Li-ion batteries with complete automatic control of all major loads. This system would have an expected life of 20 years with 25 years being likely and would have a complete installation cost of $650k, including all equipment and labor. This gives an average price of $27k per home but that includes the 54 kW master unit. The cost of the actual system installed on each home or node would be only $17k. If each house averaged 30 kWh per day and the master system averaged an additional 80 kWh per day then, in areas like Puerto Rico or the Virgin Islands, this system would be completely self sufficient with no need of the grid at all. This gives a levelized cost of energy of $.10/kWh over 20 years which is about 1/3 what people in the Caribbean have been paying for electricity and this includes the highest level of energy security. The average for all homes in southern California is 20 kWh per day so there is considerable room for slack here. Slack that may be used up by EV charging or community loads like pumps. This system could share with neighboring systems via a 430 VDC transmission line or interface directly to a grid with any set of rules you wanted to impose on grid use. It is feasible to add more nodes with less solar and energy storage if you can make up the difference with the grid, when it is working.



This graph is in kW over 3 days.

Grid Structure. Traditional grids are optimized for sending large amounts of power for long distances. Typically generation plants produce high voltage AC (around 100 kV) and send this, 3 phase, to various substations where they have transformers that reduce this to medium voltage (around 20 kV) which send this to smaller transformers for individual homes, or small clusters of homes, which step it down to 120/240 VAC split phase or sometimes to 3 phase for industrial applications. These transformers are designed to be efficient at full power so they drive the magnetization up very high (that is why they hum so loud) to allow for fewer turns on the coils to reduce copper losses. This causes lots of energy to be wasted when the transformer is running at low or zero power, which is often the case when balancing a Microgrid. This entire grid structure wastes about 12% of the energy to transmission losses. All of these transformers and the high and medium voltage transmission wires that connect them represent an enormous capital cost as well as an enormous operating cost to keep them repaired and operating. They are the first to go in a storm. When the dominant source of power is solar (or even wind) then there is really no reason to move large amounts of power long distances as the sun is pretty much available everywhere and all of the buildings have roofs which can be considered free real estate for solar panels. Each building can have a utility room for the energy power electronics along with Li-ion batteries for energy storage. The idea is that most buildings would have resources to cover their average needs but the resources required to cover all of their peak needs might be prohibitive so we create small clusters of Microgrids where there can be some sharing of energy assets. We have all grown up on the grid structure and there are a lot of assumptions that we got used to and we will have to adapt to this new scenario. We have all treated the grid as if it were infinite and each node or appliance was insignificant but, with a Microgrid, you have very limited, finite, sources of energy so you need to take control of all significant loads. That is what the T13X is for. It is the critical real time piece that guarantees that you will never exceed the capabilities of your system, even for one 60 Hz wave shape. Most of the real time fast decisions can be made automatically with no communication but high level, slower, communication is required to balance out the system, to enforce some level of fairness, to maintain priorities for critical loads and to feed accounting engines. For this we use a plug computer on each device which has Wi-fi, ethernet and Bluetooth and is loaded with the higher level software.

Cyber Security. Any system that has complete centralized control has a single point of failure and is made as a challenge to be hacked into. All of these plug computer edge devices on each node feed into concentrators that maintain servers in the cloud. The highest levels of database security are employed so the security will always be top level and up to date. However, the real security here is that none of the real time energy decisions that impact critical loads are made by computers, software, servers in the cloud or communication. Even the load shedding with the T13X demand modules is principally driven by Microgrid AC frequency which dips slightly when capacity is challenged. This even happens when the grid reaches capacity and their rotating generators slow down slightly. The entire system works as a frequency stabilizer by controlling loads, all with no communication at all. This makes the critical, keep the lights on, part of the system unhackable. Hackers may somehow breach the security of the accounting systems and some high level energy resource management but the lights, refrigerators, security systems, computers, communication systems, etc. will always keep running, regardless of what cyber security systems have been breached.

Deployment. In contrast to centralized grid developments, pieces of these Microgrids can be deployed incrementally providing immediate energy services locally. This means that the capital expenditures are also applied incrementally and the system can be augmented over time incrementally. This is a major issue. Large commercial and industrial facilities can take a similar approach but on a larger level. You could use the 54 kW 3 phase building blocks, each with their own solar and energy storage, and combine them to build a similar, but larger, structure. You could combine many versions of larger systems from many manufacturers as long as you included energy storage and control, particularly control of loads.

I can't think of any reason why the Caribbean islands would not move forward with this type of Microgrid structure. For more detail see **Transverter Microgrid**.

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