AN OVERVIEW OF TECHNICAL ASPECTS OF MINI-GRIDS

Village Electrification through Sustainable use of Renewable Energy (VE-SuRE)

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Embassy of Switzerland in India

TARA

Contributors

Dr. Andre Pittet, Consultant, Swiss Agency for Development and Cooperation

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Branding and Designing Guidance

Ranjeeta Ghosh, Jay Vikash, Development Alternatives Group

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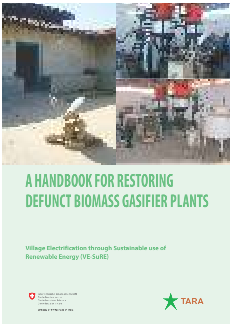

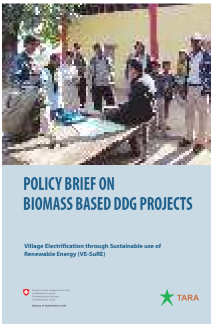

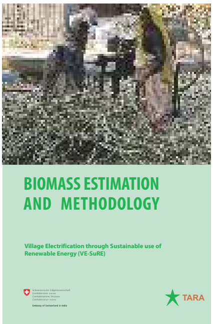

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Contents

Background

The issue of availability of energy and its access is dominating the development landscape since a few years as it is directly linked to development but has also a very strong link to the growing concerns about climate change. In this context, efforts are on-going at all levels to tap into renewable energy sources sometimes in very large installations feeding into the national or international grids. At the other end of the spectrum, there are many projects run by individuals, NGOs, small private enterprises or government agencies aiming at developing distributed generation based on renewable energies (RE).

The larger RE plants are usually handled from the planning and design stages till their operation, maintenance and management by competent professionals. On the other hand pico, micro or mini installations designed to serve local communities present a number of socio-economic challenges and are usually taken up by individuals coming from various backgrounds including social, political or economical sciences who have limited knowledge or understanding of the actual technological challenges at hand.

These notes are targeted at such individuals, involved in planning or implementing small projects where electricity is produced from renewable energy. The purpose of the notes is to present an overview of the challenges linked to the control of such systems, especially when multiple energy generating units are interconnected in a mini-grid and /or linked to a larger grid.

We shall try to keep this as simple as possible to give the reader a basic understanding of the issues and options available. However the actual implementation of any of the schemes reviewed will need inputs form competent specialists.

What do we mean by electrical "grid"?

The terms "grid", mini grids" or "micro-grids" have been used to describe very different realities, and we shall look at those before venturing onto the technical aspects of RE generation.

Let us first look at the term *"grid"* itself, as applied to electrical systems. As is of often the case now, Wikipedia [1] appears to be a good starting point. It first quotes from Kaplan [2] and defines a grid as:

"an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers."

However, the term grid is used for a large variety of networks, from very basic to extremely complex. A simple basic installation with one generating station, its distribution lines and consumers, as often implemented in decentralized renewable energy projects, would better be described as a *"generating and distribution network"* than a grid (fig.1). As explained below (from Wikipedia again [1]), a grid is normally expected to offer a certain amount of redundancy.

The structure or *"topology"* of a grid can vary considerably. The physical layout is often forced by what land is available and its geology. The logical topology can vary depending on the constraints of budget, requirements for system reliability, and the load and generation characteristics.

The cheapest and simplest topology for a distribution or transmission grid is a radial structure. This is a tree shape where power from a large supply radiates out into progressively lower voltage lines until the destination homes and businesses are reached.

Most transmission grids require the reliability that more complex mesh networks provide. If one were to imagine running redundant lines between limbs/branches of a tree that could be turned in case any particular limb of the tree were severed, then this image approximates how a mesh system operates(fig. 2). The expenses of mesh topologies restrict their application to transmission and medium voltage distribution grids. Redundancy allows line failures to occur and power is simply rerouted while workmen repair the damaged and deactivated line.

Except for some very localized distribution networks, most electrical grids have a number of generating sources attached to them. Interestingly Wikipedia highlights this in the following way in a section entitled "Redundancy and defining *"grid" [1]"*

A town is only said to have achieved grid connection when it is connected to several redundant sources, generally involving long-distance transmission.

This redundancy is limited. Existing national or regional grids simply provide the interconnection of facilities to utilize whatever redundancy is available. The exact stage of development at which the supply structure becomes a grid is arbitrary. Similarly, the term national grid is something of an anachronism in many parts of the world, as transmission cables now frequently cross national boundaries. The terms distribution grid for local connections and transmission grid for long-distance transmissions are therefore preferred, but national grid is often still used for the overall structure.

And what do we mean by "mini-grid"?

Let us now look at how the term mini-grid or micro-grid has been defined in various sources.

For example the Alternative Energy Promotion Centre (Nepal) use the phrase "mini-grid" for any Micro/mini Hydro Power (MHP) installation that has a potential to be later connected to the grid [3].

An article by Kunal Nagpal [4]of The Energy Research Institute (TERI, New Delhi), gives an *"official"* definition of mini-grids without giving sources:

Officially, a mini-grid is defined as a distributing electricity network operating at less than 11 kV, which is sometimes connected to the wider utility grid.

A number of documents about the Clean Development Mechanism (CDM) under the United Nations Framework Convention on Climate Change (UNFCCC) [5]define mini-grids for their own projects as:

"a small-scale power system with a total capacity not exceeding 15 MW (i.e. the sum of installed capacities of all generators connected to the mini-grid is equal to or less than 15 MW) which is not connected to a national or a regional grid."

Finally the Task 11 of the Photovoltaic Power Systems Programme from the International Energy Agency (IEA) [6], defines a mini-grid as:

"a set of electricity generators and, possibly, energy storage systems interconnected to a distribution network that supplies the entire electricity demand of a localized group of customers. This power delivery architecture can be contrasted with single customer systems (e.g. solar home systems) where there is no distribution network interconnecting customers, and with centralized grid systems, where electrical energy is transmitted over large distances from large central generators and local generators are generally not capable of meeting local demand."

If we go back to the previous section we can see that large electrical *"grid"* have multiple generating sources and redundancy in the distribution network (meshed network). While under the generic term of Distributed Renewable Energy Generation a number of small installations may have multiple generating sources, they normally have a distribution network topology in the form of a *"tree"* with no redundancy, and therefore less reliability.

For the purpose of these notes and based on the definitions given above, we shall retain that a mini-grid consists in one or more electricity generating units, a distribution network and at least a few consumers. This excludes single household electrification, even if some of the points described below would also apply to such installations.

Major technologies used in energy generation

Before we describe the technical aspects linked to control of distribution network parameters (voltage and frequency), we shall quickly review the major technologies used in electrical energy generation.

Synchronous Generators

Most large electricity generating plants have a prime mover that drives a rotating generator. The prime mover may be a hydraulic turbine, a diesel engine, a steam turbine, or any other system that produces mechanical energy through a rotating shaft. This rotating shaft is made to drive a generator that converts energy from mechanical to electrical form. The generator is usually a synchronous machine, rotating at constant speed to deliver an alternative current and voltage at a given standard frequency.

Induction Generators

In recent years, the use of asynchronous or induction generators for production of energy from rotating machines has developed considerably, especially for relatively small installations such as mini hydroelectric plants or wind power generators. These systems present different characteristics from the synchronous generators as will be explained in the next section on frequency and voltage control. Such generators are considered more rugged, more reliable and cheaper than the equivalent synchronous machines.

Rotating DC Generators

In a few cases, mostly for very low power in the range of a few dozen or hundred Watts, DC generators are used. This is mostly the case for systems built by hobbyist to take energy through a small hydro or wind turbine. As these are not common we shall not be concerned with such systems.

Photovoltaic generators

The direct conversion of solar energy into electricity is done through solar panels in what is referred to as photovoltaic (PV) generators. The output of such panels is in the form of a direct current (DC). The actual voltage and current delivered by such panels depends not only on the surface of the panel, its orientation and the incident solar radiation, but also on the load connected to the system.

Major technologies used in energy storage

Many of the traditional technologies for electricity generation (hydro, thermal, nuclear, etc.) are *"dispatchable",* which means that they can, to some extent[1], deliver electricity when required. On the other hand, some of the renewable energy sources, such of solar and wind power, are *"non-dispatchable",* as that they depend on the availability of the resource at a specified time (sun, wind). To take care of this characteristic it is often required, mostly for independent mini-grid, to store the energy produced in order to ensure its availability when required. Towards this a number of technologies have been developed for storage. A few a briefly described below, without going into the continuous debate of their advantages and disadvantages.

Storage in batteries

Batteries are certainly the most common technology for energy storage. They come in many different forms and capacities, with various chemistry backgrounds. They are often the simplest to integrate in a min-grid. Batteries store energy in DC form. They usually need an electronic interface to control their charge and discharge cycles. They also need more sophisticated electronic controls (rectifiers / inverters) if they have to be integrated in an AC mini-grid

Source: http://upload.wikimedia.org/wikipedia/commons/thumb/e/ee/Photo-CarBattery.jpg/300px-Photo-CarBattery.jpg

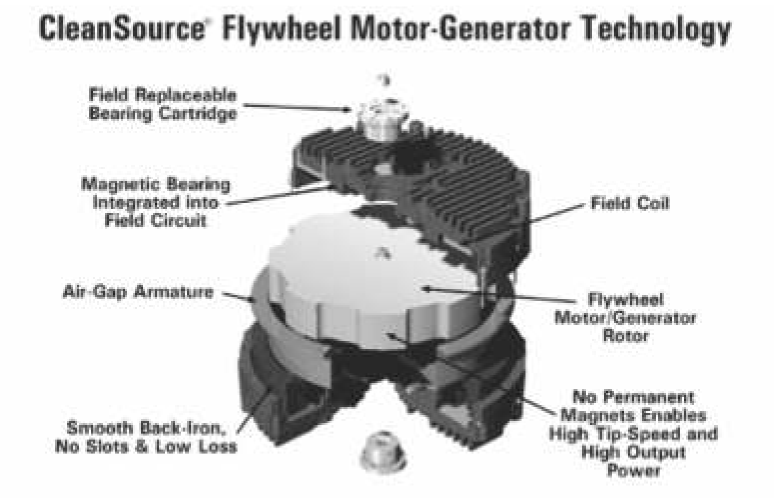
Storage in super-capacitors

Some recent developments in capacitor technologies have led to the development of super-capacitors which can now play a role of energy storage components for mini-grids. As for the storage in batteries, super-capacitors are DC elements and they need electronic control for their charge and discharge and rectifiers / inverters if integrated in an AC mini-grid.

Source: https://commons.wikimedia.org/wiki/File:Maxwell_supercapacitor_MC2600_series_2600F.jpg

Storage as kinetic energy

Some systems store energy in the form of kinetic energy by having a large flywheel accelerating during storage and decelerating while returning energy to the mini-grid. To be efficient the flywheels arrangement must minimize friction and therefore are often designed with magnetic suspension and vacuum. The wheel may be activated through an induction machine that act as a motor during storage and as a generator when returning energy to the mini-grid.



Source: http://www.thehotaisle.com/wp-content/flywheel.jpg

Storage as potential energy

Another technology used for energy storage consists in pumping water from a low level to a storage basin at a higher elevation. That water can be used later to generate electricity through a turbine-generator group. This technology implies significant investments and is mostly envisaged for large systems. It may become important with the development of very large wind and PV *"farms".*

[1] Hydro power is highly dispatchable as the power delivered can be adjusted within a short time constant of a few seconds. On the other hand the output of coal or nuclear thermal plants take long time to be adjusted and this can be done efficiently only within a limited percentage of the installed power.

DC versus AC grids

As seen above, electricity may be generated in DC or AC forms. There are ways to convert electrical energy from one form to the other.

Rectifiers convert AC to DC
Inverters convert DC to AC

By far the most prevalent is the AC grid, available as national grid in all countries.

The dispute about the merits and demerit of AC versus DC distribution is not new as it started more than 120 years ago between Edison and Westinghouse [7]. However, with increase in PV sources as well as the appearance on the market of more and more DC operated appliances, the debate is again on the front stage [8].

For a mini-grid, the choice between a DC or an AC distribution depends on the type of electricity generation, the type of storage if any, the size of the grid and the characteristics of consumers.

In relatively small mini-grids based on DC sources such a PV, it is often economical and efficient to remain with a DC distribution. This is however limiting in the type of appliances that may be used by the consumers as most of them are designed to match the norm of the AC national grid.

At present there is a trend to work on 12V DC as a number of appliances have been developed for such a voltage, usually available for a car battery. However today we see the emergence of a 5V DC standard in the form of the USB connector now being made available on new vehicles and even on board of aircrafts. This in turn encourages the development of small appliances that will operate under such standard.

Basic principles to control frequency and voltage in an AC grid.

Each country has standardized the voltage and frequency for its electrical grid. In India the national grids are expected to deliver 230 V at 50 Hz at the consumers' premises (as per the Indian Electricity Rules, 1956). It is useful to know that, when dealing with large power levels, it is preferable to work at higher voltages to avoid losses, mainly in the transmission lines. Transformers are used to convert the power between different voltage levels and high voltage lines are used for transmission. Even at the generating point, some large generators will directly produce power at higher voltage. However in the case of relatively small installations characteristic of mini-grids, power is usually generated at the standardized voltage in the case of rotating generators. In any case, the voltage is always brought down to 230V before being supplied to the premises of *"normal"* customers.

In an AC grid or mini-grid, two parameters have to be maintained or controlled:

- Frequency
- Voltage

The frequency is maintained by matching the active power generated (Pg) by all generating units to the active power consumed (Pc) by all consumers (+ losses in the system). If we generate more than consumed (Pg > Pc), the frequency will tend to increase beyond 50 Hz till Pg = Pc, while if we generate less power than required (Pg < Pc), the frequency will drop below 50Hz (a very usual occurrence in the Indian grid).

In conventional generating station using synchronous generator the active power generated is regulated by controlling the torque applied to the shaft of the rotating generator. This is done by controlling the water flow in hydro-turbines, fuel flow in diesel generating units or the steam flow in steam turbines (which ultimately requires also indirectly control of the combustion in thermal plants, or fission in nuclear plants).

The voltage is maintained by matching what is known as reactive power generated (Qg) to the reactive power required by the load (Qc)[2]. Reactive power is required by inductive loads such as motors or any appliance using magnetic coils and can be produced by a generator or by capacitive loads. As this form of power generates losses in the transmission network without resulting in useful energy, utilities requires large users to compensate as much as possible their reactive power by installing suitably dimensioned capacitors to match their requirements. However there always remains some mismatch between generated and consumed reactive power.

In conventional generating station using synchronous generator the reactive power generated is regulated by controlling the excitation current in the generator.

In generating plants using induction machines as generator, the reactive power (and therefore the voltage) has to be controlled by switching capacitor banks as the induction generator itself is not able to produce the required reactive power.

[2]Reactive power is a concept used by engineers to describe the background energy movement in an Alternating Current (AC) system arising from the production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Devices which store energy by virtue of a magnetic field produced by a flow of current are said to absorb reactive power; those which store energy by virtue of electric fields are said to generate reactive power. [10]

Basic principles to control voltage in an DC grid

In the case of a DC (mini) grid, the key parameter to control is the grid voltage. Most DC mini-grids are associated with photovoltaic panels and include some energy storage in the form of batteries or super capacitors. In such case, the system always includes control electronics modules to optimize the energy production (maximum power point tracking; MPP) and control the energy storage as well as the power distribution to the consumers. This controller takes also care of maintaining the voltage of the distribution network.

Control of various grid configurations

In this section we shall give an overview of the control strategies for various grid configurations from simple to more complex.

At the outset it is important to realize that on a national grid the presence of a very large number of loads, each representing a very small fraction of power consumed, helps in smoothening the curve of consumption over time. Every switching on or off of an appliance will be reflected as a very small percentage variation in the overall load on the grid, allowing for a relatively smooth correction of the power generated to avoid frequency and voltage shifts. The case is quite different in small independent installations (mini-grids) where a single load may represent a significant percentage of the generating plant capacity. Therefore controlling the frequency and voltage on a mini-grid presents its own challenges.

Standalone or island operation of a single generator AC mini-grid

Such a system has only one electricity generator, a distribution network and a number of consumers attached to it.

Dispatchable energy

A typical example of a single generator AC mini-grid with dispatchable energy would be a village having a micro-hydro plant to generate its electricity. The plant has just one generator, either synchronous or induction type.

As mentioned above, frequency has to be controlled by matching the active power produced to the active power consumed (load). This may be done in two ways:

- By controlling the power produce by mean of adjustment of the hydraulic valve position, either manually or automatically (fig. 3).

- By ensuring a constant power consumed, using an Electronic Load Controller (ELC). The ELC is an electronic system which ensures that the excess of power produced by the generator is destroyed in a ballast load (fig. 4).

Note: The ELC is a very fast acting device as it switches on or off the ballast loads using electronic switches. The time-constant of such systems is in milliseconds.

On the other hand, if the frequency control is done by activation of the hydraulic valve, this is a slow process with a time constant of a few seconds. Such a slow correction would normally lead to unacceptably large deviations of the rotating speed and therefore of the network frequency and voltage. To reduce these fluctuations, it is common to have a large flywheel installed on the shaft or the turbine-generator group. This flywheel prevents fast changes in the rotating speed, thus adapting the systems to the time constant of the valve control mechanism and therefore limiting the frequency and voltage excursions.

The voltage has to be controlled by matching the reactive power produced to the one required by the loads. If we have a synchronous generator, this control is taken care of by the Automatic Voltage Regulator (AVR), normally an integral part of the generator. When dealing with an induction generator, this control has to be done using switched capacitor banks. If the approach is to use an ELC, such systems are available for induction generators and take care of both voltage and frequency regulation.

We took the example of a mini or micro hydroelectric plant, which is convenient as its output power level can be controlled through the water inlet valve. Similarly a gasifier-based generating plant produces also dispatchable energy as the combustion can be adjusted to regulate the output power level.

Non dispatchable energy

As mentioned earlier, some of the renewable energies such as solar or wind are non- dispatchable: the power output is not directly under the control, of the system's operator. These installations usually include an energy storage element such as batteries to take care of the uncertainly about power availability. The frequency control is done by diverting the excess power from the generating unit into the batteries, or when the production is less than the consumption, by drawing the required extra power form the batteries to supply it to the consumers. This is done through the electronic control unit associated with such systems which includes the required inverters to produces AC power from the DC link (fig. 5). This electronic control unit also takes care of the voltage regulation.

It is important to keep in mind that once the batteries are full, they cannot anymore absorb and store the excess of energy produced. In the case of solar photovoltaic panels, this is not an issue as the electronic control system can change the operating point to reduce the power generated and ensure that it exactly matches the power consumed. However for wind generators, there is no simple way to reduce the power produced and it is common in such installations to have a dummy load connected to the system to be able to dissipate any extra energy when the batteries are fully charged.

Standalone or island operation of a single generator DC mini-grid
In such installation, the electronic control unit takes care of voltage regulation in the distribution network. The problem of dissipation of excess power produced in the case of wind generator remains, as described above.

Standalone or island operation of AC mini-grid with multiple generators
In this case we have two or more generators connected to the distribution network. The first problem is to synchronise the generators before they can be interconnected. This implies bringing them to the same voltage, frequency and aligning their phase. It may be done manually but is usually achieved with an electronic synchronising unit (fig. 6). Each generator has also its own control of active and reactive power as described above (manual or automatic). It is important to understand here that, for example, we cannot have both generators trying to control the frequency, or they would have to do so in a collaborative manner. The same would apply for the voltage and reactive power.

Let us take a very simple case: we have two micro-hydro power (MHP) plants both connected to the same mini-grid. They are at a few kilometres distance and are manually operated. If, after synchronisation, both operators are trying to control the frequency independently of the other, they may end up working *“against”* each others. In such case, it would be advisable to have one operator in charge of maintaining voltage and frequency. He would not only make the required adjustments on his plant, but also give instructions to the operator of the second plant to fix the operating point of that plant. This is what would be called a hierarchical control with a master (plant 1) and a slave (plant 2). This requires communication between the two generators, which is very easy if both are in the same location, but may be more complicated the plants are far apart. The concept of hierarchical control, explained here for a manual control, may be applied exactly the same with automatic controllers. But such systems must be designed for master / slave operations and imply the availability of a communication channel (fig. 6).

Droop regulation

For systems with an automatic control of both active and reactive power control, it is common to work with the concept of "droop regulation". In a simple way we can state that the control is done in proportion of the error in frequency or error in voltage. To illustrate this let us say that for a mini-hydro plant, the controller is designed to follow a frequency regulation such that the nominal frequency is 50 Hz and the accepted deviation is + or – 4%. This implies that the frequency should remain between 48 Hz and 52 Hz. Towards this the droop controller would act in such a way that, when the frequency drops to 48 Hz, the hydraulic valve would be totally open to produce the maximum power. When the frequency is 50 Hz, the controller would set the valve to produce half the power, and when the frequency touches 52 Hz, the valve would be closed so as to produce no power at all. A similar approach is taken for the voltage control and the reactive power.

Such controllers can work in parallel as long as the droop characteristics of all controllers are matching (same deviation for 0% and 100% power generation). They do not need a separate communication channel as the distribution network itself (mini-grid) carries the required parameters (frequency and voltage).

If a DC generator (PV panels) is also connected to such a mini-grid, its control electronic system must be designed to match the characteristics of the other droop controllers.

Grid connected operation of a single generator mini-grid

When the regional or national grid is available at (or near) the site of a mini-grid, it is often advantageous to interconnect them so that the excess power produced at the mini-grid can be fed to the large regional or national grid. This obviously implies that the mini-gird is functioning at the frequency and voltage of the main grid.

In such a situation, for small installations, the main constrain is to ensure synchronization of the mini-grid to the larger one before interconnecting. This implies adjusting the mini-grid voltage, frequency and phase to be exactly aligned with the main grid before connecting. This is done nowadays mostly through automatic controllers. Once the two girds are interconnected, the frequency will be fixed by the main grid and the generator of the mini-grid can be usually allowed to produce to its maximum power. The reactive power must still be controlled locally by the AVR for synchronous machine, by the ELC for induction machine or by the electronic control unit in case of DC generators such as PV panels.

When the system functions in such manner with part or all of the generated power supplied to the main grid, the control unit must be capable of handling critical situations like disconnection when the main grid goes down or the grid parameters go outside the permitted range. These are not only technical issues but very critical issues of safety that have to be taken care of and are integral part of the contract with the main grid operator.

From the above it must be clear that the control systems used for island operation and for grid connected operation are different even if they may be combined in a single controller.

Grid connected operation of a mini-grid with multiple generators

The presence of more than one generating unit in the mini-grid to be interconnected with a main grid does not change the control strategy. The controller must be able to ensure complete synchronism between mini and main grid before interconnecting them, and it must provide all the features to ensure safe operation including during critical situations. An example of a hybrid multi generator mini-grid configuration with a DC link and battery storage is given as illustration in figure 8.

Large regional, national or international grids

In very large grids, the control issues become more complex as the grid topology itself is much more complicated with redundancy and therefore options in routing the power from the production centres to the consumers. The challenges in such grids are numerous, but the basic principles remain the same: balancing the production and consumption of both active and reactive power at every instant. The way to do this remains the same as explained above, however the complexity is orders of magnitude higher than in mini-grids. Besides maintaining voltage and frequency, the control centres must also ensure a proper balance of load in the various transmission lines and optimize the cost of generation while ensuring the availability of energy not only on the spot, but also for the next days, weeks or months.

The situation of the regional grids in India is such that the power generation is always short of the demand. Therefore the frequency regulation can only be done by limiting the consumption to the actual power produced at any time. This is done by the infamous *"load shedding"* operations where the utilities disconnect as many branches of the grid as required to match the load to the available power produced.

It is much beyond the scope of this note to deal with the control of such large grids, but it may be interesting to realize that the introduction of renewable generating units such a wind or solar power in a relatively large scale creates new challenges for grid managers. Indeed, if the share of non-dispatchable energy sources increase in the energy mix, the other generating units must be able to cope now not only with load changes but also with variations of production from the renewable energy generating units. These variations are not controllable, only partially predictable and may be rather sudden. On the other hand some of the conventional technologies for generating energy such as thermal and nuclear cannot change quickly their power output. They have very slow time constants and cannot adapt to compensate sudden changes in production from wind or solar farms. This calls for some innovative approaches in grid management including innovative energy storage technologies.

Conclusion

Through these notes we have shown that the control of mini-grids frequency and voltages is based on the basic principle of matching power produced to power consumed. However we also explained why controlling a single generator working in an isolated mini-grid (island mode) is different from controlling a multi-generator mini-grid. Similarly, when passing from island mode to grid connected mode, the control paradigm change and consequently the equipment required also change. It is important for all stakeholders to understand this in order to have realistic expectations when "up-grading" existing plants of when planning to connect them to a larger grid.

Works Cited

1.) “Electrical Grid,” 04 04 2013. [Online]. Available: http://en.wikipedia.org/wiki/Electrical_grid. [Accessed 05 04 2013].

2.) S. M. Kaplan, Smart Grid. Electrical Power Transmission, The Capitol.Net Inc, 2009.

3.) “Mini-Grid Support Programme,” 2008. [Online]. Available: http://www.aepc.gov.np/index.php?option=com_content&view=article&id=147&Itemid=170. [Accessed 05 04 2013].

4.) K. Nagpal, “Smart Mini-Grids: Innovative solutions to combat energy shortfall,” 25 Oct 2012. [Online]. Available: http://www.trust.org/alertnet/news/smart-mini-grids-innovative-solutions-to-combat-energy-shortfall/. [Accessed 05 04 2013].

5.) “Renewable electricity generation for captive use and mini-grid,” [Online]. Available: http://cdm.unfccc.int/filestorage/4/1/J/41JF08WD9MSEB5YLHTZ6KVAPUC7XNQ/EB61_repan18_Revision_%20AMS I.F_ver02.pdf?t=TUt8bWtzMG4xfDDdPTU7vyYFx310W7RrvyDn. [Accessed 05 04 2013].

6.) “IEA PVPS Task 11 - PV Hybrids and Mini Grids,” [Online]. Available: http://www.iea-pvps-task11.org/id34.htm. [Accessed 05 04 2013].

7.) Wikipedia, “War of Currents,” 09 April 2013. [Online]. Available: http://en.wikipedia.org/wiki/War_of_Currents. [Accessed 18 April 2013].

8.) “Plugging into DC,” IEEE Powr & Energy magazine, no. November-December, 2012.

9.) “AC Coupling vs DC Coupling – Off Grid Solar,” Stand Alone PowerSupplies, 20 October 2012. [Online]. Available: http://standalonepower.com.au/portfolio-6/off-grid-solar-ac-coupling-vs-dc-coupling. [Accessed 08 04 2013].

10.) The National Grid Company plc, “An Introduction to Reactive Power,” October 2001. [Online]. Available: http://www.nationalgrid.com/NR/rdonlyres/43892106-1CC7-4BEF-A434-7359F155092B/3543/Reactive_Introduction_oct01.pdf. [Accessed 18 April 2013].

ANNEXURE

BASICS OF ELECTRICAL CONCEPT FOR BEGINNERS

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Voltage and Current

The terms voltage and current are regularly coming up during discussions on electrical systems. These are very basic parameters of a circuit and for those who are not at all familiar with it may be useful to map those on a hydraulic equivalent. The current in an electric circuit can be compared to the flow of water in a pipe, while the voltage is the equivalent of the pressure in the pipe. Therefore, we can understand that we can have a voltage present without any current circulating (equivalent of a situation with a closed tap). This voltage is necessary for being able to use the electric power by allowing a current to circulate in the circuit (without any pressure in the pipe nothing would flow). The presence of a voltage indicates a potential to extract power from the source. Voltage is measured in Volts (V), while current is measured in Amperes (A). It is a very common mistake to state that *"the current in India is 230V"*... it is the Voltage that is (or should be) 230 V.

Alernative (AC) and Direct (DC) currents

It is also very common in electrical installations to mention about AC current and DC current. Ac stands for Alternating Current, while DC is for Direct Current. Again, taking out hydraulic equivalent, a Direct Current is like a continuous flow of water in the pipe. The flow of current in continuous, in the same direction. Typical example of DC electrical circuits are the battery operated systems such as torch lights, electrical circuits from the battery of your car, or the current produced by a solar photovoltaic panel. On the other hand, in an Alternating Current (AC) circuit, as the name indicates, the direction of current keeps alternating. This correspond to an oscillating current in the circuit, with the electrons in the wires moving forward then reverse and again forward and reverse, etc. The direction of movement of the electrons keeps changing 100 or 120 times per second. The number of complete oscillations per seconds is called the frequency of the AC current and is expressed in Hertz (Hz). It is usually of 50 Hz (Europe, Asia) or 60 Hz USA and some other American countries.

Figure 1 shows a typical voltage of a DC electrical circuit, in this case a continuous stable 12V.

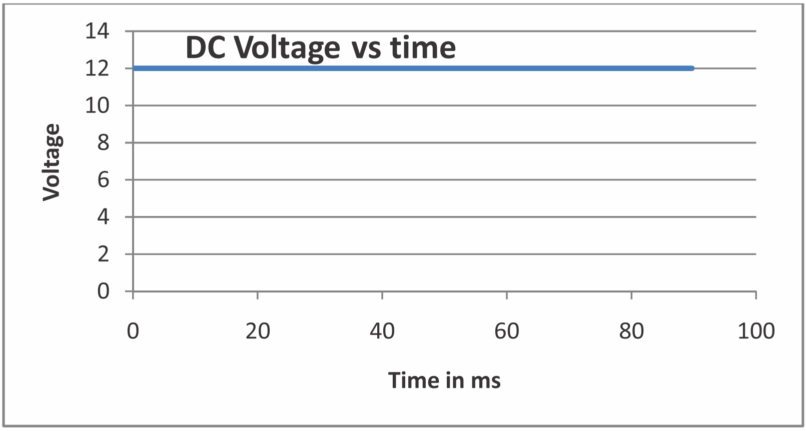

Figure 1: continuous voltage in a DC circuit

Figure 2 shows an AC voltage of 230V at a frequency of 50 Hz. You may notice that the voltage is a succession of sinusoidal waves, each of a duration of 20 milliseconds.

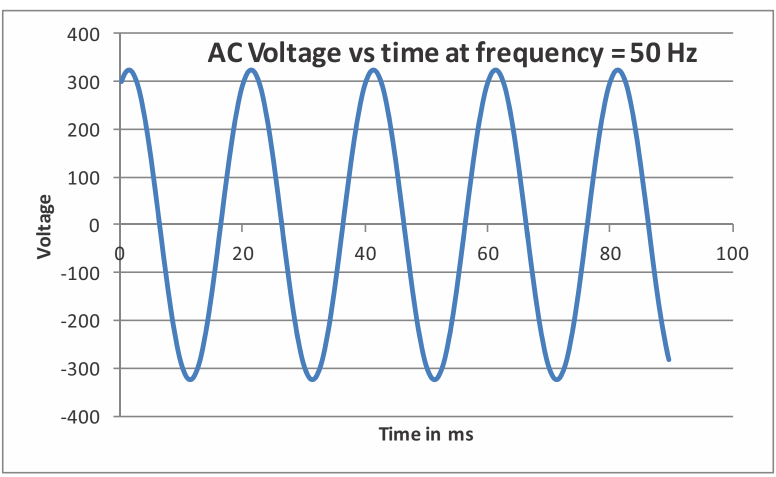

Figure 2: oscillating voltage in an AC circuit at 50 Hz

On figure 3 we can see a similar AC voltage waveform, but with a frequency greater (or faster) than 50 Hz, resulting in the waveforms being more *“compact”* or *“squeezed”*.

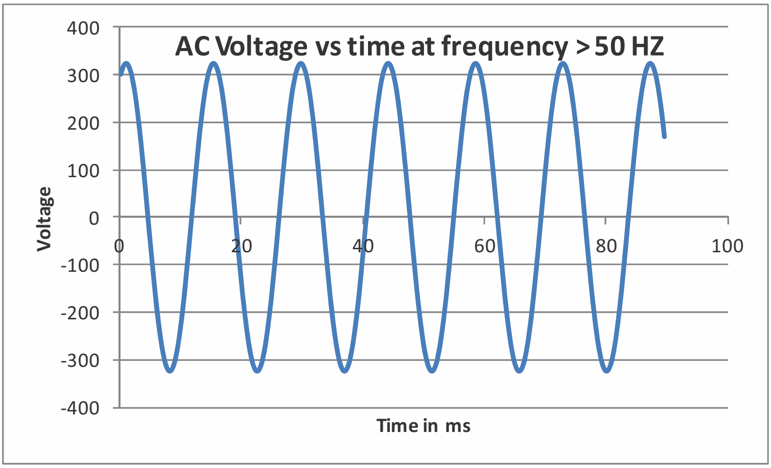

Figure 3: oscillating voltage in an AC circuit at a frequency above 50 Hz

There are both advantages and disadvantages for AC and DC circuits, but at present most electrical distribution systems in villages, towns and cities use AC. There exist also electronic units that can convert AC into DC (rectifiers) or DC into AC (inverters).

Active and Reactive Power

The power delivered by a generator or consumed by an appliance is an instantaneous value. When we mention power, we always imply by default the Active Power. It is measure in Watts (W) or Kilowatts (KW) which is nothing but 1000W. This must not be confused with the Energy, which is the actual work done and is calculated as the product of the power and the time during which that same power was delivered. The energy is measured in KWh, often referred to as just "units" when it comes to your electricity bill. One KWh is the energy consumed by an appliance of 1 KW (like some heaters) operated for one hour, or say a 100 W bulb left ON for 10 hours. To illustrate the difference between power and energy, let us take a weight lifter. He or she may lift 230 Kg of iron in a second or so and thus demonstrate his/her power. However, he or she will quickly drop the iron on the floor and will finally not have done much of work or delivered much energy. On the other hand, I regular construction site worker may only lift a dozen of Kgs of bricks on his/her head and bring them up three floors, but by doing so all along the day, he/she will have done a significant work and spent quite some energy doing so.

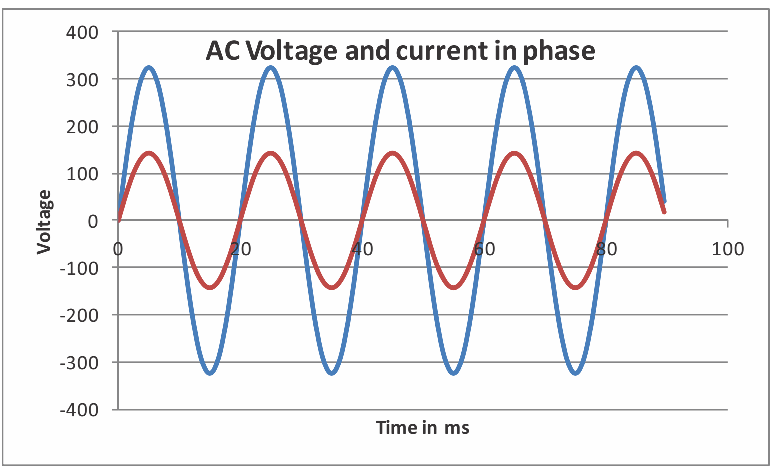

Figure 4: AC voltage and current with a resistive load (in phase)

In electrical circuits, the Active Power is calculated by multiplying the voltage by the current. In DC circuit this is very simple as both voltage and current have continuous values when the load is constant. However for AC circuits, the situation is different as the Voltage is always oscillating. For a simple load like a heater, the current at any instant is directly proportional to the voltage at that instant. We could say that the current (red) is exactly *"in sync"* with the voltage (blue) as shown on figure 4.

We also say that voltage and current are *"in phase".* Therefore when multiplying voltage and current at each instant we obtain the curve shown on figure 5.

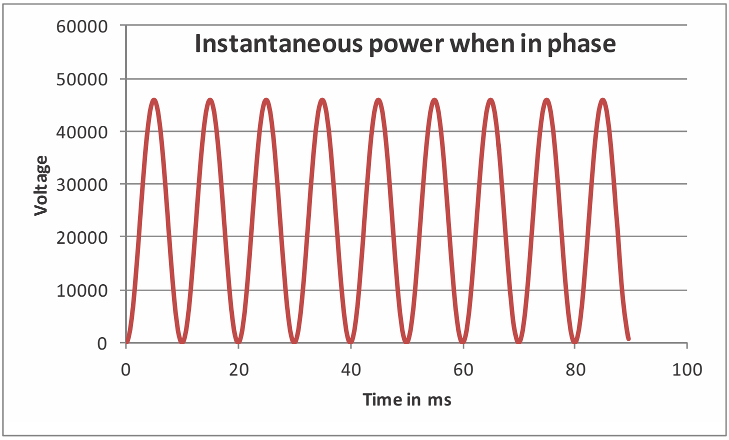

Figure 5: Instantaneous power in a resistive AC load

We can see that the instantaneous active power is always positive. Now if we have a different kind of load like an inductive coil, the current is no more in phase with the voltage. IN an extreme case of absolutely inductive load, it may be out of phase as shown on figure 6.

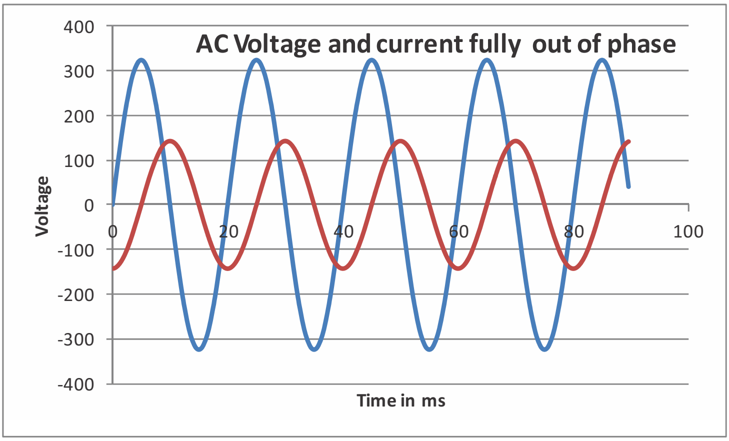

Figure 6: AC voltage and current with a purely inductive load

If we now calculate the instantaneous power we can see on figure 7.

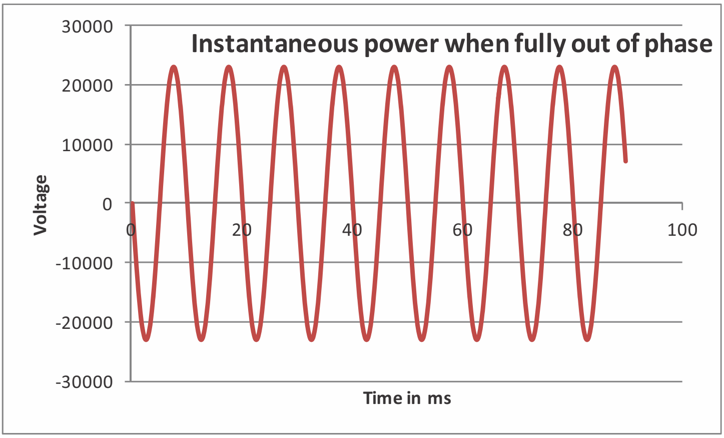

Figure 7: Instantaneous power in a purely inductive load AC load

That is now oscillate between positive and negative values with an average of zero. This is what is referred to as Reactive Power as in fact such a complete offset between voltage and current does not produce any useful work.

Most appliances lead to a current that is neither fully in phase nor fully out of phase with the voltage, as shown for example on figure 8.

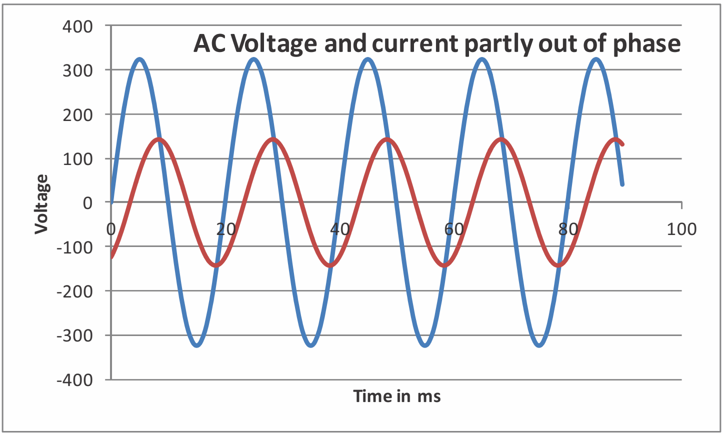

Figure 8: AC voltage and current with a partly inductive load

This results in both Active and Reactive Power. As the concept of Reactive Power is not easy to grasp, we shall just remember that such power leads to circulation of current in the circuit and consequently losses, without contributing to useful work or energy. It is therefore usually best to try to minimize the reactive Power.

NOTES

NOTES

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Embassy of Switzerland in India

Climate Change and Development
Chandragupta Marg, Chankayapuri
New Delhi - 110021
Phone: +91 11 4995 9570
Email: delhi@sdc.net
Website: www.swiss-cooperation.admin.ch/india

TARA

B-32, Tara Crescent
Qutub Institutional Area
New Delhi - 110016 (India)
Tel.: +91-11-26544100
E-mail: tara@devalt.org
Website: www.devalt.org