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Energy Network Communications and Expandable Control Mechanisms

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Abstract

A modular, expandable network requiring little or no calibration is something that is well sought after and would offer great benefits when used for distributed energy generation. Intelligent and adaptive control of such a network offers stability of supply from intermittent sources which, to date, has been hard to achieve.

Key to the effective use of such control systems is communications, specifically the exchange of commands and status information between the control systems and the attached devices. Power-line communications has been used in various applications for years and would offer a good mechanism for interconnecting devices on a power grid without the expense of laying new cabling.

By using clusters of devices managed by an IEMS (Intelligent Energy Management System) in a branching network fashion (not unlike the grid itself) it would be possible to manage large numbers of devices and high speed with relatively low bandwidth usage increasing the usable range of transmission. Implications of this include improving network efficiency through managed power distribution and increased security of supply.

1 Introduction

The concept of an expandable power network which can be altered in real time without any significant reprocusions for consumers is something that would benefit the utilities and the consumers alike. However, such a network would require significant interactivity between devices and grid areas requiring further development of communications and control systems. The following introduces the key concepts and technologies which are discuss herein.

Powerline Communications:

Powerline communciations uses multiple overlayed frequencies to transmit data along transmission lines. Each frequency can then be filtered out and interpreted to yield the transmitted data.

Powerline communications has been considered and used for many applications over the years including broadband internet, grid monitoring and most recently smart metering for buildings. However, its usage has always been limited by factors inherent to the grids themselves and it is often used in combination with other types of communications. Companies such as Landis+Gyr[1] and Elster Solutions[2] offer smart metering solutions using some degree of powerline communications, whilst Echelon[3] offers a development platform for powerline networking grid devices.

Despite the interest and work done in this area, systems that rely entirely on powerline communications, from generation to consumer, are virtually non-existant and as such there is scope for the development of new technology and techniques in this area.

Smart Meters:

The smart meters currently being installed allow for near real-time monitoring of household or business power usage, scheduled handling of certain devices, for example washing machines, heaters, etc., and the option to remotely connect or disconnect devices.[1,2] All of this is done on the understanding that it can save the consumer money on electricity bills.

The hope with this (and other) work is that devices can be developed which can monitor and regulate the flow of power into a property without the need for user interaction, however, this requires a great deal of interactivity between devices as well as some knowledge of how each device behaves.

Micro-Grids:

The main focus of most power grid research has been the greater integration and interactivity of grid components. Grid components in this case meaning properties, via smart meters, and the utilities. As part of this work micro-grids are being considered to be potentially grid-independant/child systems which connect to the parent grid only when necessary and otherwise rely on their own generation and power storage. The same mechanisms that allow the effective use of stand-alone generation and storage however, have implications on larger grids.

2 Expandable Power Grids

Within this work an expandable power grid is described as;

> *"A power grid that can operate equally well at both a micro and macro-grid level without requiring significant changes,"*

the concept being that such a grid can operate modularly in a larger grid structure or independently. The key factors to creating a successful expandable grid system are;

- the inclusion of an Intelligent Energy Management System (IEMS),
- the ability for each device to communicate with the IEMS,
- the capacity for the IEMS to enact measures to control all attached generation and storage, and some connected loads,
- that each device contains a mechanism for reporting power usage and status including it's priority.

The easiest way to look at this is to view the micro-grid case and then look at the considerations that would need to be made to expand from micro to macro.

In a completely independant micro-grid we must assume that there is sufficient **average** power generation to support the attached loads at any given time. In the case of the majority of renewables this is difficult without some form of energy storage which must therefore also be included within the micro-grid structure.

If such a grid is to be based entirely on renewables such as wind and solar, which are inherently intermittent, the energy storage is essential to maintaining the required average power output. Regulation of such storage devices, in conjuction with the control of non-vital loads (loads that can be safely disconnected and reconnected without incident) will help to use the generation more effectively and efficiently. An empirical structure for such a micro-grid is shown in Figure 1.

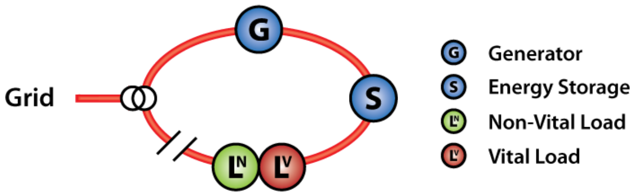

Figure 1: empirical Representation of a Semi-Independant Micro-Grid

The "vital loads" in Figure 1 represent those devices that cannot be disconnected remotely, whereas the "non-vital loads" can be disconnected or reconnected without incident. Although the micro-grid has been shown having an external grid connection this would only be true where the grid was being used as a backup power source in the case of insufficient primary power.

For ease of installation, powerline communications would connect all attached devices allowing for monitoring and control. This eliminates the need for additional cabling which should in turn help to reduce the expense of such installations.

3 Concept Systems

IEMS: The concept IEMS's structure is described by the block diagram shown in Figure 2.

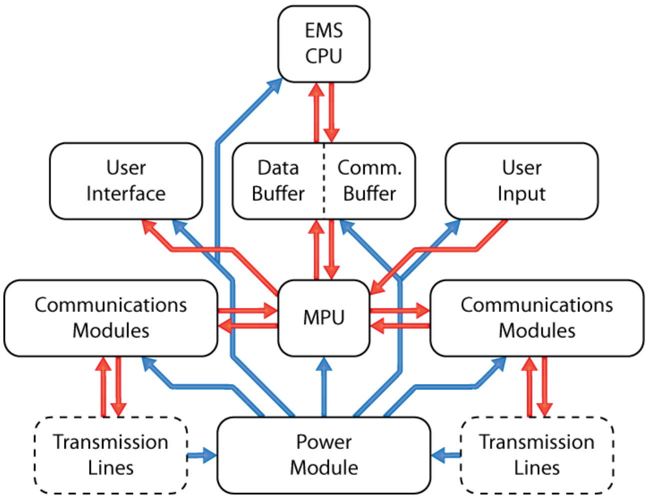

Figure 2: IEMS Block Structure

The blue paths represent power connections and the red represent data connections. Each IEMS contains two main processors. The most powerful being the EMS CPU because this is the processor required to run the potentially complex EMS algorithms. The MPU is the second processor which mediates all data transactions and commands. Two synchronous buffers separate the processors transferring devices specific data and commands. User input and interfaces are provided but should be secondary to the EMS algorithms.

The block diagram also illustrates the different hardware levels that exist within the device with the EMS algorithm being autonomous at the highest level. This diagram includes 2 communications modules which may not always be required depending on the application. The second communications module is required for the bilateral version of the IEMS which links across grids and is used in the mass distribution concept which will be described later.

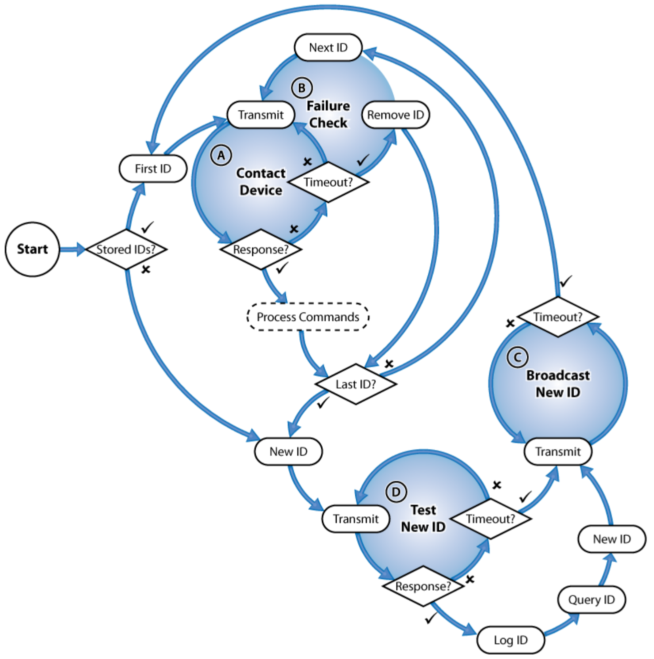

Figure 3: IEMS Communications and ID Assignment Algorithms

The flowchart shown in Figure 3 represents the concept communications system platform embedded in the IEMS that handles connections to all attached devices. Devices are assigned IDs as they are detected which then serve to facilitate communications between the IEMS and the device.These algorithms run in the firmware layer that interfaces the main IEMS algorithms and the devices.

In reference to Figure 3;

A: "A" attempts to contact all discovered devices in sequence, upon successful contact data and commands are exchanged between the device and the IEMS. In the event of a failed contact control is passed to B. Once all IDs have been checked, control passes through to D

B: "B" will remove the failed ID from the system to prevent it from slowing operations down and progress ID forward passing control back to A unless the removed ID is the last ID, in which case control passes through to D

C: "C" broadcasts the next available ID for detection by any devices which do not already have an ID. Once this operation has timed out, control passes back to A

D: "D" attempts to contact the next unstored ID, if a response is received then that ID is added to the ID list. Whether a response is received or not, control then passes to C

Devices: Each connected device will need to have attached or embedded hardware capable of interfacing with the IEMS. The concept device structure is described in Figure 4.

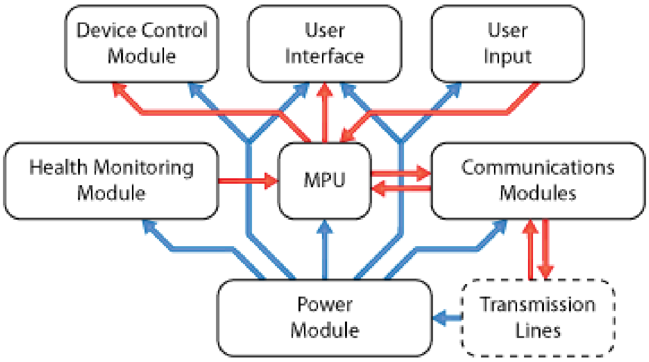

Figure 4: Device Block Structure

The device structure is a good deal simpler than the IEMS as it does not have high level control algorithms and only requires a single communications module. User input is still an option, however, this will depend on the placement of the device.

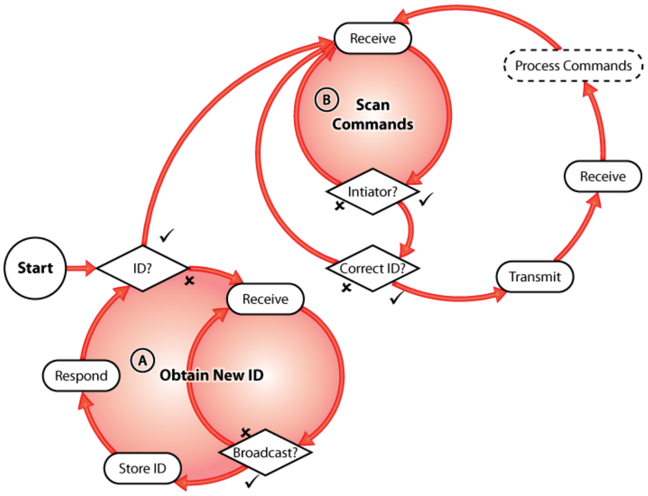

Figure 5: Device Communications and ID Assignment Algorithms

In reference to Figure 5;

A: "A" interfaces with process C from the IEMS algorithms and will pickup and store the new ID being broadcast when the device is first activated.

B: "B" monitors the transmissions from the IEMS, on receipt of an initiator command code it will check the attached ID and, if correct, it will respond and proceed with the exchange of data and commands with the EMS.

For each round transmission and reception event there is a sub process which must be observed to maintain the fidelity of the transmission. During data encoding, error correction information will be added to the data to help maintain data integrity, this is used to determine successful transmission during the reception stage. This occurs on all transmission-reception pairs.

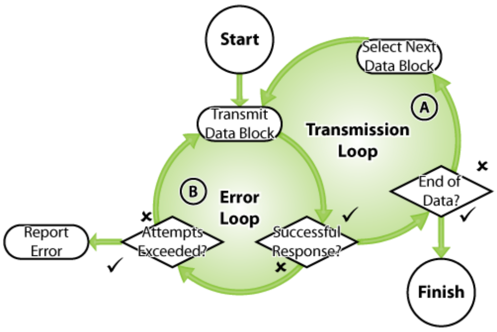

Figure 6: Transmission Process Flowchart

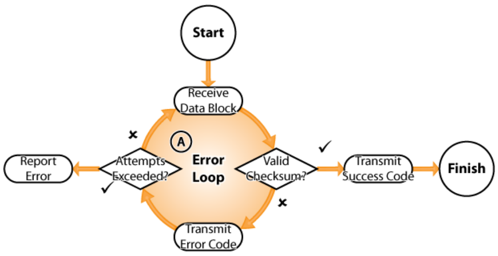

Figure 7: Reception Process Flowchart

Both these mechanisms will report errors in the event on non-receipt, however the error management algorithms have not been included here. In most cases there will be numerous pieces of data to be transmitted, therefore containing the transmission loop, where as the reception process is the same process repeated for each incoming transmission.

It should be noted that whilst using these mechanisms the IDs are volatile and will be erased if there is a loss of power. This was deliberately included as a part of the methodology. Any device that suffers a loss of power will reconnect and will have its ID re-assigned by the IEMS. This was included as part of the failure response mechanism allowing the IDs of failed devices to be taken by new ones as they are added and preventing the number of IDs exceeding the number of devices. Also, should a device which had previously had an ID be added to an IEMS where that ID was already present it would cause problems similar to clashing IP addresses on a computer network.

The bandwidth in this concept system has deliberately been kept low for two reasons;

1. by designing both devices and IEMSs to operate at low bandwidths necessetates that they be very economical with their data resulting in reduced processor demands and specifications, resultin in a more inexpensive device as a whole,
2. bandwidth is related to the frequency used for transmission, as the bandwidth increases so must the transmission frequency, low frequencies transmit further down transmission lines therefore reducing the bandwidth helps to increase transmission range.

The losses associated with frequency can be linked to the reactive losses in the inherent capacitance of the transmission lines themselves. Since both transmission lines and the ground can both be considered conductors they can be considered to be a large parallel plate capacitor. An equivalent circuit approximation of a transmission line is shown in Figure 8.

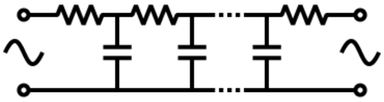

Figure 8: Transmission Line Approximation Equivalent Circuit

Reactive power generated by a transmission line with the capacitance C would be;

$$Q = I_{RMS}V_{RMS} \tag{1}$$

$$= \frac{V_{RMS}^2}{X} \tag{2}$$

where;

$$X = \frac{1}{2\pi Cf} \tag{3}$$

therefore;

$$Q = 2\pi CfV_{RMS}^2 \tag{4}$$

The generation of this reactive power causes additional losses and, in the case of a data signal, signal degradation. As such reducing the frequency should improve transmission range for the same signal quality.

4 Expanding the Scope

Bilateral IEMSs: The bilateral IEMS mentioned earlier is the mechanism that allows for the expandability within these systems. Each IEMS would be able to handle a certain number of connected devices but there will be a limit due to the use of IDs. This limits the usefulness of a single IEMS unless there is a way to utilise them in a branching structure.

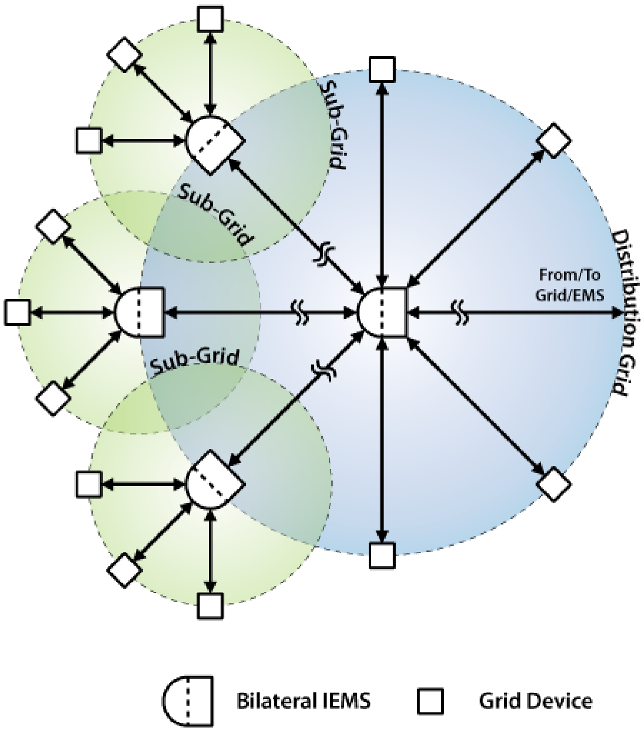

Figure 9: Bilateral IEMS Grid Schematic

This is where the bilateral IEMS is useful because it connects to two different network branches, in general on either side of a substation. A bilateral IEMS is in essence a IEMS with a device interface on the back. On one side are the devices that the IEMS controls and on the other side is a device interface connected to a "superior" IEMS. A bilateral IEMS can be used with or without the "superior" IEMS.

The main purpose of a bilateral IEMS structure is to allow for greater coordination of resources. On a most basic level, a superior IEMS can command a subordinate IEMS to vary its output and in turn that IEMS will command its connected devices (and subordinate IEMSs) to increase their outputs or if that is not possible return an error saying why. Using this method each IEMS can have a limited number of connected devices and is responsible for delegating tasks to the IEMSs below it. A basic explaination would be the superior IEMS demands power, the subordinates go and find it.

This has additional benefits with the introduction of local storage for distributed generation in that it can help to reduce losses within transmission lines and therefore improve the overall efficiency of the grid. In Figure 9 A & B represent local grids that are geographically close while C represents a distant grid. If, when either A or B exceeds their local resource (including storage), power output is increased from the neighbouring grid (B or A respectively), rather than C, then transmission losses are reduced and efficiency is increased. If power loss in transmission lines is assumed to follow;

$$P = I^2 R \tag{5}$$

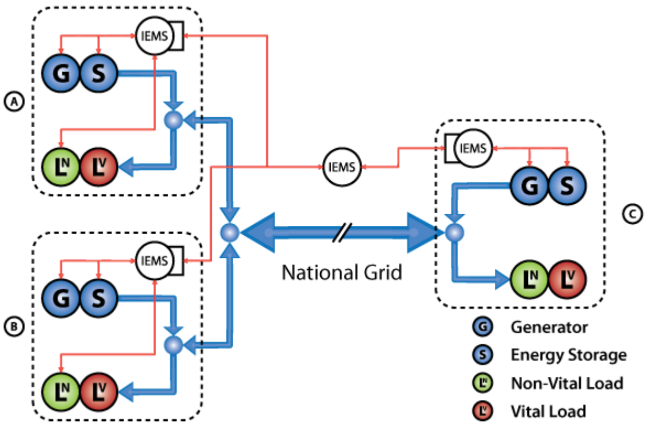

Figure 10: Bilateral IEMS Grid Schematic

where;

$$R \propto L \tag{6}$$

and L is the length of the transmission line, then an increase in the power being transmitted down a long transmission line will cause substantially higher losses than transmitting that power down a shorter line for the same voltage. Transmission at lower voltages is less efficient because of the proportionally higher currents however it is still more advantageous to move power locally than nationally in most circumstances. It may seem counter intuitive to potentially have some areas storing an excess while others are draining storage to suppliment a loss, but for limited periods it may improve overall network efficiency. In order for this to work however controllable storage, generation or loads must be available in each local grid.

The nature of a bilateral IEMS makes it possible to create a cascading network structure where a cental IEMS can control the entire infrastructure. However the changeable nature of the grid due to the remapping IDs makes creating a complete network picture a little difficult. Included in the concept is a mechanism that allows for individual devices to be queried for information. Should a user or IEMS request information about a specific address then that request is relayed between IEMSs until it reaches the device. Retrieved information is that passed back through the network to the requesting IEMS.

Figure 11 shows an IEMS Cascade Infrastructure. Each circle represents an IEMS while squares represent attached devices. On each level of the cascade the EMSs work to maintain the stability of the grid beneath them, working from a local or even building level to a national one. Since each EMS is treated as a device by the ones higher up it makes the control mechanisms simple, and due to the reduced amount of information required to operate in this way, bandwidth for these applications can be relatively low without needing to waste MPU time on compression.

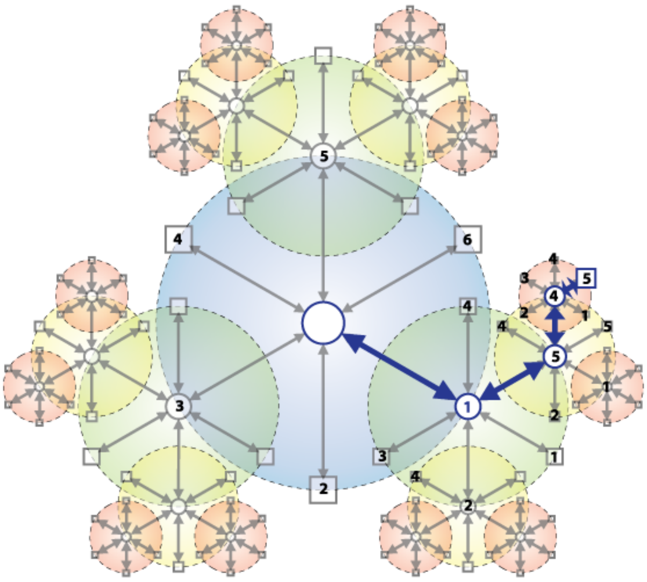

Figure 11: Multi-level EMS Cascade

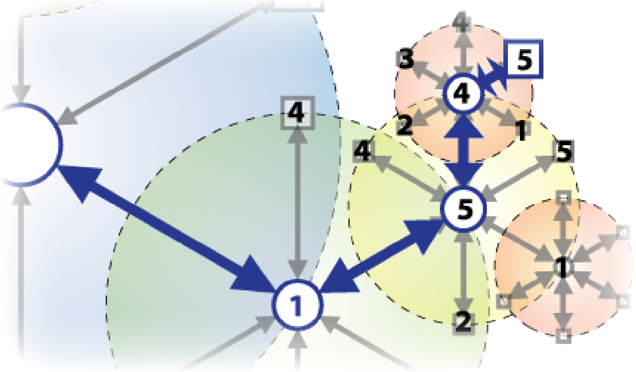

Figure 12: Close-up of Relational Addressing Numbers

Figure 12 shows how a cascade address would be created. Each address indicates the path taken through the network, however, its quite possible that the length of these addresses would vary substantially from region to region. This mechanism would likely only be utilised by the user interface for determining device specifications, most of which would come from a database referencing product code numbers transmitted along the network. Constantly updating information about devices would require too much bandwidth so as a device was created it would need to be registered with the appropriate databases so that successful queries can be made.

5 Conclusions

This paper illustrates the benefits of and the necessary steps to create and intelligent energy management system and related hardware.

The use of IEMSs in a cascade infrastructure, such as the one described previously, would allow for a very versatile and almost infinitely expandable network capable of operating at low bandwidth and long range. The use of low bandwidth may limit the data capacity of such an infrastructure, however it should increase the range of transmission where the signal integrity is unimpared. Inceasing range reduces the need for extra hardware, such as repeaters, and improves response times within the network.

Intelligent control of energy storage makes it possible to selectively route power within a network. This prevents large, lossy transfers from other areas of the network, improving overall grid effciency. This is only possible using distributed/local generation and storage but could have implications for the entire grid.

Storage plays another vital role in the ability to regulate the power being fed into a grid to prevent overpowering. This can prevent excessive losses by absorbing the necessary fraction of power output upon transmission. It can also do the reverse, discharging power to fill a deficit. Combined it can help to maintain a safe operating level, minimising grid fluctuations. Regulated output makes best use of rated lines and helps to prevent damage to local grid systems.

Overall, Intelligent system control coupled with a low bandwidth, cascading architecture should provide noticeable benefits to all users of the grid through increased efficiency and more reliable supply. The low-bandwidth hardware IEMSs and devices are inexpensive to produce and install with no extra cabling required because of the powerline communications.

References

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4. Harrison, A.; *"The Essence of Electric Power Systems;"* (1996)