LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie
et du Commerce extérieur

Office de la propriété intellectuelle

Luxembourg, le **28.01.2013**

Attestation de prise en compte

№ 92140

Brevet No **92140** , déposé le **25.01.2013**

Titulaire(s): **UNIVERSITÉ DU LUXEMBOURG**
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Le Ministère de l'Economie et du Commerce extérieur, Office de la propriété intellectuelle, atteste de la prise en compte de l'intervention de **Demande de brevet national**, enregistrée le **28.01.2013**, sous le numéro **9**.

Remarque : Lampe Sigmar Ref.RUES004LU

Pour Lex Kaufhold
Chargé de la direction
Office de la propriété intellectuelle

Marc BESENIUS

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UNIVERSITÉ DU LUXEMBOURG

№ 92140

Luxembourg, le 25 janvier 2013

Ministère de l'Economie
et du Commerce extérieur
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19 - 21, Boulevard Royal
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Your ref:
Our ref: RUES004LU

Dépôt de demande de brevet d'invention luxembourgeois
« DECENTRALISED POWER SUPPLY FOR SMALL AND MEDIUM USER FACILITIES »
au nom de: UNIVERSITE DU LUXEMBOURG

Monsieur le Directeur,

Par la présente nous vous faisons parvenir les documents suivants constituants la demande de brevet d'invention susmentionnée, en trois exemplaires :

- requête
- mémoire descriptif

Nous vous prions de bien vouloir confirmer la date ainsi que le numéro de dépôt.

La traduction des revendications suivra dans le meilleur délai.

Veuillez agréer, Monsieur le Directeur, l'expression de nos sentiments distingués

Sigmar Lampe
Conseil en Propriété Industrielle
Chargé de valorisation
Affaires juridiques

MINISTÈRE DE L'ÉCONOMIE ET DU COMMERCE EXTÉRIEUR * GRAND-DUCHÉ DE LUXEMBOURG * 21

Pour Lex Kaufhold
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Grand-Duché de Luxembourg

Ministère de l'Economie et du Commerce extérieur
Direction de la Propriété Intellectuelle

Demande de brevet d'invention

Loi du 20 juillet 1992 portant modification du régime des brevets d'invention

Dépôt 03/09

Cadre réservé à l'administration

Demande No:	Date de réception:	Date de dépôt:

A. REQUÊTE

Le(s) demandeur(s) requièr(en)t la délivrance d'un brevet d'invention pour l'objet décrit et représenté dans les pièces annexées

1. Titre de l'invention:
DECENTRALISED POWER SUPPLY FOR SMALL AND MEDIUM USER FACILITIES

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2. Demandeur — Référence (si connue):

Nom et prénom ou dénomination sociale: **Université du Luxembourg**
Adresse: **162a, avenue de la Faïencerie**
L-1511 Luxembourg

Téléphone: **466644-6182** Téléfax: **466644-6313** E-mail: **sigmar.lampe@uni.lu**

Etat dans lequel est situé le domicile ou le siège du demandeur: **Luxembourg**
☐ Un (Des) demandeur(s) supplémentaire(s) est (sont) indiqué(s) sur une feuille en annexe

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3. Mandataire(s) du (des) demandeur(s) — Référence: **RUES004LU**

Nom(s) et prénom(s): **LAMPE Sigmar**
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☐ Un (Des) mandataire(s) supplémentaire(s) est (sont) indiqué(s) sur une feuille en annexe
☐ Le(s) demandeur(s) déclare(nt) élire domicile auprès du (des) mandataires

Type de mandataire (cocher une **seule case**):

☒ Mandataire agrée ☐ Représentant commun ☐ Avocat ☐ Employé

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4. Adresse postale au Grand-Duché de Luxembourg:

Le(s) demandeur(s) requièr(en)t que les communications du Service soient envoyées à:
☐ l'adresse du demandeur mentionée à la rubrique 2
☒ l'adresse du (des) mandataire(s) mentionnée à la rubrique 3
☐ l'adresse suivante:

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5. Désignation d'inventeur(s)

Nom et prénom :	**PETERS, Bernhard**
Adresse :	**Ernzener Weg 12A** **D- 54668 Prümzurlay**
Nationalité :	**allemand**

☒ Un (Des) inventeur(s) supplémentaire(s) est (sont) mentionné(s) en annexe
☐ Une désignation d'inventeur(s) est / sera produite séparément

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6. Déclaration de priorité:

Demande No:	Date de dépôt: Déposant(s) :	Pays:

☐ Une (des) déclaration(s) de priorité supplémentaire(s) est (sont) mentionné(s) sur une feuille en annexe

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7. ☐ La présente demande est une DEMANDE DIVISIONNAIRE de la demande suivante:

Numéro:	Date de dépôt:

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8. ☐ La présente demande est fondée sur la DEMANDE INTERNATIONALE (PCT) suivante:

No de publication:	Date de dépôt: Date de publication:

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9. ☒ Il est demandé L'ÉTABLISSEMENT D'UN RAPPORT DE RECHERCHE D'ANTÈRIORITÈS

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10. ☐ Il est demandé la VALIDATION D'UN RAPPORT DE RECHERCHE D'ANTÉRIORITÉS effectué sur la demande suivante:

Demande No:	Date de dépôt: Déposant(s)	Pays:

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11. Abrégé

Il est demandé de publier l'abrégé de la demande de brevet accompagné de la figure No: 1

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12. Annexes:

- ☒ Description de l'invention (3 exemplaires) — Nombre de pages: **22**
- ☒ Revendication(s) (3 exemplaires) — Nombre de revendications: **20**
- ☒ Dessin(s) (3 exemplaires) — Nombre de dessins: **10**
- ☒ Abrégé (3 exemplaires)
- ☒ Dessin à publier avec l'abrégé (joindre une copie séparée) No: **1**
- ☐ Traduction des revendications:
- ☐ Feuille avec demandeur(s) supplémentaire(s)
- ☐ Feuille avec mandataire(s) supplémentaire(s)
- ☐ Feuille avec inventeur(s) supplémentaire(s)
- ☐ Désignation d'inventeur(s) séparée
- ☐ Feuille avec déclaration(s) de priorité supplémentaire(s)
- ☐ Document(s) de priorité (3 exemplaires)
- ☐ Traduction de document(s) de priorité (3 exemplaires)
- ☐ Document(s) de cession du droit de priorité
- ☐ Autres:

B. PROCÈS-VERBAL DE DÉPÔT

La présente demande de brevet d'invention a été déposée au Ministère de l'Economie et du commerce extérieur, Direction de la Propriété Intellectuelle, à Luxembourg,

en date du à heures.

Le(s) déposant(s) / mandataire(s):

Sigmar Lampe
Conseil en Propriété Industrielle
Affaires juridiques
Université du Luxembourg

Pour le Ministre de l'Economie et
du commerce extérieur,

Lex Kaufhold
Chargé de direction
Direction de la Propriété Intellectuelle

Annexe 1 - Indications des inventeurs supplémentaires

Nom et prénom:	**HADJI-MINAGLOU, Jean-Régis**
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Nationalité :	**allemand**

DECENTRALISED POWER SUPPLY FOR SMALL AND MEDIUM USER FACILITIES

Technical field

The present invention relates to a method of communicating operation modes between a user facility control unit at a user facility and a utility grid control unit of a utility grid. In particular, it relates to a decentralised method of communicating operation modes between a user facility control unit at a user facility with renewable energy supply and a utility grid control unit of a utility grid.

Background

The world-wide energy consumption has almost doubled since 1980 despite efforts towards energy saving and efficiency. This trend is supposed to continue for the decades to come so that major energy crises with electricity cuts and shortage of petrol or gas are anticipated. Furthermore, an ever increasing consumption of fossil fuels significantly contributes to further emissions of greenhouse gases and consequently to global warming in conjunction with catastrophic climate changes. These impacts are reduced to a large extent through utilisation of renewable energy sources for and within decentralised user facilities.

Prior art

US patent application 2009088991 A1 discloses management of electricity for large buildings and campus. Generation of renewable energy for, exportation of the renewable energy from, importation of utility generated energy to, and consumption of energy at, a facility are monitored in substantially real time to provide for substantially real time management and reporting of energy performance of the facility. Monitoring of environmental conditions and facility operations of the facility, also in substantially real time and time correlated with the energy monitoring, is performed to further enhance the management and reporting of the energy performance of the facility.

US patent application 2009094173 A1 provides an intelligent power unit including a battery, a power switch, and a control unit. The control unit receives price information and

operates the power switch based on the price information to charge the battery during periods of relatively low electrical energy prices. During periods of relatively high electrical energy prices, the control unit causes the energy stored in the battery to be used to power attached loads. The price information provided to the control unit can be actual price information regarding the cost to generate electrical power, estimated price information, or contract price information. Hence, the concept proposed in US 2009094173 A1 aims at storing power during low price periods and using it during high price periods. It is a feature of the intelligent power unit of US 2009094173 A1 that it can be used to shift a utility's electrical power demand in time. When the intelligent power unit is coupled to solar energy panels, it has an additional flexibility in that it can charge a battery or power household load(s) with the power produced by solar energy panels. This is done so that intelligent power controller will prioritize using power produced by the solar energy panels before using power supplied by a utility.
International patent application WO 0227892 A1 proposes fuel cells to produce electrical power within a local or utility grid. Furthermore, patent Number WO0227892A1 emphasises redistribution of electricity in a local grid or utility grid. Additionally, control units organise distribution of electrical energy.

International patent application WO 2011124657A1 describes a method of managing the consumption and distribution of electricity in a user facility, wherein the user facility is connected to an electricity supply grid and the user facility comprises a grid-connected on-site generator. The method comprises determining on the basis of locally measured conditions whether the electricity supply grid is oversupplied or undersupplied with electricity and modifying the flow of the electricity within the user facility based thereon. The method further provides for storing imported energy in a thermal energy storage for later use. Moreover, the electrical load characteristics of the user facility may be altered to intentionally create a demand for electrical power from an oversupplied electricity supply grid.

Disadvantages of the prior art

A welcome side effect of conventional systems and methods may be the financial advantage, meaning the energy is stored during low price periods and used during high price periods, and that energy stored during periods of an over-supplied grid is available during periods of under-supply. However, under these conditions the grid has to grow with the increasing consumption of electrical energy.

In US 2009094173 A1, the interaction with the utility grid needs a user profile or similar criteria for decision making that is not disclosed.

Technical problem to be solved

Accordingly, it is an object of the present invention to provide a self-sufficient and self-contained economic energy supply of electricity and heating/cooling for small and medium user facilities. Moreover, it is an object of the present invention to overcome or alleviate the disadvantages of the previously known state of the art energy supply systems.

Summary of the Invention

The invention provides a self-sufficient (i.e. energy autonomy on the microscale) and self-contained (i.e. providing a source of electrical energy not connected to the power grid) economic energy supply of electricity and heating/cooling for small and medium user facilities to a large extent for which the transfer of energy to and from the utility grid is minimised. Throughout this document the expression user facility refers to family houses and small and medium sized companies and workshops. The latter have a large share in the energy consuming market, and thus, replacing consumption of both electrical and heating energy by renewable energy sources decreases the dependency on ever shrinking fossil fuels and contributes significantly to reduce greenhouse gases and global warming. Furthermore, electrical energy generated at user facilities with decentralised devices releases the utility grid that therefore offers large capacities for redistribution of electrical energy to energy intensive regions and for communication between suppliers and consumers. As mentioned above, the release of the utility grid and minimised transfer of energy to and from the utility grid is based on communication links between the utility grid and the local user facility through which demands and supplies from both sides are determined. The user facility is equipped with the following devices for both electrical and thermal energy:

- Electrical energy generation

- Electrical energy storage
- Electrical energy consumers
- Thermal energy generation
- Thermal energy storage
- Heating/Cooling
- Control unit

These devices installed at user facilities generate, store and consume both electrical and thermal energy so that primarily the requirements of the user facility are met. The requirements of the user facility may be derived from known profiles or are acquired through monitoring of user behaviour in the past, and therefore, allow provision of energy and control for near-future events. The latter is achieved by the control unit that communicates with the devices and operates them dependent on given targets such as minimum energy prices, available energy or delayed operation for non-system relevant devices e.g. washing machine. Each user facility is connected to the utility grid and monitors its temporal performance indicating an under- or over-supplied utility grid. For an under-supplied grid the control unit allows feeding into the utility grid provided an energy surplus is available at the user facility that is detected by the control unit of the user facility. During periods of an over-supplied grid the control unit at the user facility may allow utilizing the surplus on energy e.g. direct consumption or storage dependent on the current demand of devices at the user facility. These capabilities of the control unit are further enhanced by self-learning algorithms based on neural networks that generate a typical and average user profile of the user facility, and thus, facilitates local control by anticipating near future needs of the user facility.

The current patent includes apart from electrical energy also thermal energy for heating and cooling purposes. Thus, an integral approach towards generation of energy based on renewable sources and consumption is emphasised in the current patent. Furthermore, the algorithm proposed in this patent is not reduced to management of only electrical energy, but extends also to the management of thermal energy for heating purposes. The control unit includes also elements of self-adapting algorithms that derive profiles for generation and consumption of the user facility, and thus, facilitates control anticipating near-future requirements by feed-forward control.

The present invention does not use the batteries solely for economic purposes. In particular, it does contribute to spreading renewable energy.

The present invention is not limited to fuel cells to produce electrical power within a local or utility grid. Furthermore, the present invention aims at a self-sufficient electrical and thermal energy supply of user facilities and consequently to a release of the utility grid. Additionally, the self-adaptable control concept of the current invention secures first and foremost a sufficient supply of electrical and thermal energy within the user facility that is known by a provided or generated profile for storage, generation and consumption of energy. Only when these demands are covered, export to an utility grid is considered of which the current status is known to the control unit of the user facility through communication links. Furthermore, the algorithm of the present invention includes also elements of self-adapting learning that derive profiles for generation and consumption of the user facility, and thus, facilitates control anticipating near-future requirements by feed-forward control.

The present invention promotes a self-sufficient concept to generate electrical and thermal energy on the premises of a user facility. The present invention aims at a significant release of the grid, and therefore, provides large capacities for the future by installing a self-sufficient energy concept at user facilities. Furthermore, the algorithm of the present invention includes also elements of self-adapting learning that derive profiles for generation and consumption of the user facility, and thus, facilitates control anticipating near-future requirements by feed-forward control.

Brief Description of the Drawings

Fig 1 illustrates the general set-up including self-sufficient user facilities that are interconnected by the present utility grid and connected to a control unit.

Fig 2 is a diagram of electrical power generation and consumption in conjunction with electrical energy storage for a representative household.

Fig 3 shows a representative user facility equipped with devices for generation, storage and consumption of both electrical and thermal energy.

Fig 4 is a diagram of the tree-like hierarchical organisation of the cost calculating algorithm.

Fig 5a is an illustration of the physical cluster tree topology of the communication network in normal configuration.

Fig 5b is an illustration of the physical cluster tree topology of the communication network after a reconfiguration caused by a link loss.

Fig 6 is a flowchart of local sub-tree establishment and maintenance.

Fig 7 is a flowchart illustrating the utility calculation and association handling.

Fig 8 is a flowchart showing the power flow influencing decision.

Fig 9 shows a Laboratory prototype of the present invention.

Detailed description of the Invention

The core of this invention, therefore, deals with a decentralised self-sufficient and economic renewable electrical and thermal energy supply for user facilities e.g. family houses. The concept promotes generation and storage of renewable energy where it is consumed. Hence, the utility grid is released to a large degree, and thus frees capacities for present and future demands. Current requirements for distribution of wind energy from the north e.g. wind parks and solar energy e.g. solar parks from the south within western Europe is met immediately without further extensions of the existing power network. Under these conditions the utility grid is released of almost the entire load concerning user facilities and is charged with a minimal load of energy exchanged between user facilities.

Fig 1 exemplifies the general set-up comprising user facilities 11 to 16 that are interconnected by the present utility grid 3 and which are connected to a utility grid control unit 20. To this effect user facility control links 21 to 26 are provided between the utility grid control unit 20 and each of the user facilities 11 to 16. Moreover, the user facilities 11 to 16 may be self-sufficient.

The user facilities are equipped with one or more means for electrical power generation and storage. This may be extended to a degree, such that entire self-sufficiency may be achieved as exemplified in Fig 2.

Fig 2 is a diagram of electrical power generation and consumption in conjunction with electrical energy storage for a representative household. It is assumed that the household is equipped with a permanent renewable power supply of 0.35 kW, a photovoltaic panel of typical 20 m^2 with an overall efficiency of 0.12 and a battery pack to store electrical energy. The power consumption of a representative household was provided from TU Clausthal-Zellerfeld during a winter day and the solar radiation data is provided by the Joint Research Centre in Ispra, Italy for the representative winter month of December. This represents a worst case condition also concerning solar irradiance. Furthermore, the electrical energy storage was assumed to be empty. Fig 2 depicts the above-mentioned profiles during duration of 24 h. During the night the energy storage is charged by the permanent electrical power supply. During wake-up and breakfast the electrical energy is reduced, because the permanent power supply is not sufficient and solar power generation is still negligible. During the day the storage is charged by the photovoltaic panels. The stored energy is used during the evening hours to a large extend that empties the energy storage almost entirely, however, leaves it with some reserve capacity to start the cycle again during night.

The current set-up also fulfils its self-sufficiency during summer because the photovoltaic power generation then increases by a factor of 3 to 4. The surplus of electrical energy is fed into the grid, and thus is available for consumers such as industry as mentioned above.

Heating was excluded from the current evaluation, however, because heating is assumed to be provided by solar panels in conjunction with a heat pump that increases the power consumption of the household marginally. It could be compensated for by a slightly increased permanent renewable power generation or a larger area of photovoltaic panels in conjunction with slightly higher energy storage.

However, under economic conditions, a self-sufficiency of app. 80-90 % is achievable. Consequently, the utility grid is released by the same percentage of the daily load attributed to households. This newly freed capacity may be used to transport energy from wind or solar parks to cover the remaining 10-20 % of energy to households, if no entire self-sufficiency is installed.

Alternatively, self-sufficiency may be exceeded so that a large number of user facilities generate a surplus of electrical energy for which the utility grid serves as a device for transport. It transports energy to user-facilities that are not self-sufficient and to energy-intensive region such as industrial areas. The latter may also be supplied through the grid from any kind of power station that preferably rely on renewable energy such as wind or solar parks, however, may also include conventional thermal or nuclear power stations during an initial transition period. Electrical energy during periods of an over-supplied grid can be stored due to storage devices at the user facilities. The above-mentioned operation modes are surveyed and controlled by a unit that connects the user facilities, and therefore, is supplied with the current status of each user-facility.

The facility can supply the utility with active and/or reactive power in function of the needs, taking into consideration either the frequency and the voltage magnitude of the utility or the setpoints sent by the utility management via the communication network.

Wired and/or wireless communication media are used to allow light communication infrastructures and redundancy as well. Through the smart metering of the relevant data like the power supplied into or consumed from the utility, as well as the weather measurement data, statistics and correlations with the weather conditions can be performed and monitored on the control screens of the utility management. The invention is a technical and financial support for the privatisation of the public energy supply market. It contributes to the evolution of micro-systems steadily aggregating towards interconnected decentralized power systems.

Within the current invention each user facility represents a self-sufficient unit to a large extent that may achieve entire self-sufficiency or even generate a surplus of energy dependant on the technology installed. Hence, a user facility is equipped with devices for generation and storage of both thermal and electrical energy. Consumers of both thermal and electrical energy are assumed implicitly to be existent. It includes general appliances such as TV or lightning in households and machines and any other equipment in small and medium sized enterprises. Consumption of thermal energy is predominantly represented by heating during winter and air conditioning during summer, however, may include also thermal energy as process energy for production purposes. Generally, onsite devices include literally all appliances at the user facility that consume both electrical and thermal energy. In addition, equipment that serves as an energy generator such as sources of renewable energy e.g. wind and solar parks fit also seamlessly into the current concept, because they cover a remaining demand of user facilities managed by the control unit. Hence, a user facility is regarded as a self-sufficient unit, of which the operation is controlled by a unit as depicted in Fig 3.

Fig 3 shows a representative user facility 11 equipped with user facility devices 111 to 116 for generation, storage and consumption of both electrical and thermal energy. The user facility 11 is connected by the present utility grid 3. Within the user facility 11, a user facility control unit 120 is connected to the utility grid control unit 20 via a user facility control link 21. Each of the user facility devices 111 to 116 is connected to the user facility control unit 120 via a dedicated user device control link 121 to 126. In the example illustrated in Fig 3, the user facility devices are arranged as follows: electric energy generation 111, electric energy storage, electric energy consumers 113, thermal energy generation 114, thermal energy storage 115, and heating/cooling 116.

Contrary to often applied technology, electrical power is not fed into the grid 3, but first and foremost is used to cover the demand of the user facility 11. The same applies to the thermal energy that produces heat, is utilised primarily at the user facility 11 for heating and cooling. This concept appears as logic and provides the base for self-sufficiency of the user facilities. Feeding both electrical and thermal energy first into a utility grid and then redistributing it again to user-facilities increases unnecessarily the load of the grid and contributes to additional losses. Only if the demands of the user facility are satisfied, a surplus of energy is fed into the utility grid to be re-distributed to user facilities demanding energy. Thus, the generation of energy and consequently the installed devices is demand rather than profit driven.

This invention makes the distinction between controllable and un-controllable user facility devices. The latter include devices that need electrical energy when switched on such as refrigerators or lightning. Controllable devices are characterised by a delayed consumption of electrical energy such as washing machines or dish washers. For these devices a maximum delay period is set after switching on, during which they are operated, so that their operation is triggered by the control algorithm at times when a surplus of energy is available.

As above-mentioned the concept of self-sufficiency relies on devices for generation and storage of both electrical and thermal energy. Both devices serve to cover the demand of the user facilities. In order to be independent of time-varying energy production as is the case of solar panels during night, an equipment to store energy is required. It stores energy during these periods in which production exceeds the demand and provides energy during periods when the generation is not sufficient to satisfy the demand of the user facility. In case that both generation and storage are not sufficient to satisfy the demand of the user facility, it will be complementary supplied by the utility grid.

Communication structure

Any operation mode is communicated between the local control unit 120 of the user facility 11 and the control unit 20 of the utility grid 3. The communication between the interconnected devices is managed by software algorithms that control the energy generators in conjunction with the distribution of energy and the consumers. In order to improve the controllability, part of the algorithm is developed as a self-learning unit based on neuronal networks or fuzzy logic. During an initial period the self-learning unit will learn the consumption behaviour of the user facility that results in a typical and average profile. Similar profiles will also be generated for generation and storage characteristics of both electrical and thermal energy. These profiles may span periods on one day or may extend to periods as long as a year to accommodate seasonal changes in particular heating during winter and cooling during summer. Based on these behavioural profiles, the demands and needs for generation, storage and consumption may be anticipated hours or days in advance, so that appropriate actions are taken well before the event occurs.

The design and implementation of the controller is done in a distributed way to enable a collaborative response of available resources to demand scenarios according to a locally determined cost-benefit ratio. The decision to commit local resources is derived from the state of the components defining the local power flow, e.g. the state of charge of a battery or the supply capabilities of a PV cell converted into a cost factor and is compared to the cost of failing to satisfy pending power requests.

To achieve this, the participating supply and consumer components in a given region, i.e., the network neighbourhood visible to the participants, are arranged in a logical tree structure in a first step of the algorithm execution:

Pure consumers or suppliers are always located as leaf nodes, while components capable of decisions affecting the routing of the power flow, as battery controllers, constitute the forks or links to higher levels in the tree leading to the top-level controller, acting as a gateway connecting to non-participating regions of the power grid.

The aggregation of the cost depending power balance is done on the resulting tree-like network formed by the ensemble of the available actors, i.e. power sources and sinks equipped to participate in the energy management system (EMS).

The cost is always built with a reference to maintain a local equilibrium of power demand and supply, consequently the effective cost for a potential power tap is available at the root of any sub-tree.

The controller of a component is equipped with a communication modem, which can use any available medium as a local or wide area network built on Ethernet, Powerline or wireless.

In case of communication loss the local controller falls back to the normal droop controlled mode as derived from the frequency as well as the voltage magnitude deviation of the AC line.

Admission of new participants to a local sub-tree is initiated by this participant through broadcasting of requests and authorised by the local controller node first to answer this request. Authentication can be done by a symmetric key scheme, with the key incorporated into the communication module. This key can also be used to encrypt the data transfer, if desired and computationally feasible on the controller platform used.

As shown in Fig 5 the robustness of the communication network is ensured by dynamic reconfiguration of the participants in case of a lost link, i.e., the ability to reconnect by selection of a new router.

The role of the gateway to the distribution power grid can thus be reassigned to other suitable nodes ensuring redundancy in the cross connection.

The relevant data given by the smart metering of the power produced by the power units, the power consumed locally, the power supplied into the utility, the energy produced and consumed, the incomes related to the energy sold, as well as the data given by the weather measurement station are stored over the time on a storage device. This information is always available and can be used to provide statistics and correlations with the weather conditions, numerically and graphically on the control monitor. That gives to the consumer the opportunity to know about its electrical and thermal power consumption and to adapt his consumption behaviour accordingly. The information is also forwarded to the utility manager for supervision, maintenance and future developments purpose.

That way the facility learns also the consumption habits of the local consumers and can adapt the power flow between the facility generation, storage and consumption units together locally as well as with the utility and the other facilities globally.

Devices to generate, store and consume electrical and thermal energy are specified as follows:

The power converters can provide AC as well as DC depending on the units that they are connected to. For example on the one hand as the PV panels produce DC current, they supply through a DC-DC conversion the battery set that provides a DC voltage. On the other hand both units running in DC supply together through a DC-AC conversion the utility that requires an AC voltage. In addition the DC-AC converter is reversible, i.e. it is able to feed energy from the utility back to the facility if necessary and recharge for instance the battery set,

One or more converters can be installed depending on the level of redundancy wished for the facility in case of failure.

In case several converters are installed the nominal power of each can be different in order to optimise the efficiency of the facility, which runs at different power levels, i.e. at part as well as full load.

The losses of the power units are an additional source of thermal energy that is sent to the heating system of the facility.

Each unit participating in the power distribution algorithm has to be equipped with a microcontroller and a communication module, though for simple leaf class devices with only on/off capabilities a communication module with analogue-digital and digital-analogue converters and firmware enabling remote access is sufficient.

The microcontroller for root node devices is equipped with sensor and actuator capabilities for monitoring and control of the power component and performs the logic necessary for the algorithm execution. It is programmed in such a way to ease program and parameter updates. The program also contains a device profile to enable the dynamic formulation of the cost functions.

The communication module is capable of connecting to neighbouring nodes through the locally available medium, such as Ethernet, Powerline, GSM/GPRS or a wireless network and supports at least the two lowest ISO layers PHY and MAC to enable the logical network organisation through the connected microcontroller.

<u>Description of concurrent processes algorithms implemented in each node</u>

The algorithm described below is implemented in each participating power supply, consumer and storage node. It enables these nodes to organize in a tree-like hierarchy, communicate their nominal and actual capacity and actuate control commands to the underlying power units based on the decisions derived from the local power balance accounting. All processes are running concurrently and communicate through a modem with other nodes; local information is shared between processes.

1. Local sub-tree establishment and maintenance:

In the following, reference is made to Fig 6. Nodes listen to incoming messages containing identification of other nodes, advertising their capabilities (as power supplier or consumer, capable of storage) and decide to attach to them as a child node, depending on their status (not already attached to an active node). As these advertisement messages originate from the root node (i.e., the node connected to the public power grid) the establishment of a hierarchy (tree) is ensured. Simple nodes, acting as suppliers/consumers without storing capabilities independently advertise as children nodes if they are still not attached.

To avoid unauthorised participants each node's communication modem is equipped with a symmetrical key, used to encrypt and decrypt messages, consequently preventing unauthorised participation in the protocol.

2. Utility calculation and association handling:

As shown in Fig 7, each node will cyclically go through its list of attachments to calculate the available utility in the visible sub-tree. The available utility is regularly advertised to parent nodes and used by the receiving nodes to update their list of suppliers and consumers. To avoid listing unavailable nodes in the local directory, each relationship entry in the list has a time to live associated, after its expiration the node will actively try to verify the responsiveness of the node, otherwise will cancel the entry.

3. Power flow influencing decision:

Fig 8 is a flowchart of the power flow influencing decision. Each node that is capable of a power flow influencing decision, i.e. controlling a storage device which can be charged or discharged, listens to utility requests from neighbouring nodes. These request come with a price offer which is compared with the local cost calculated per energy unit (i.e., kWh).

The cost calculation of a State of Charge for a battery preferably comprises:

- Deviation from 50% State of Charge (considered optimal);
- Quantification of lost sales (local undersupply);
- Quantification of lost utility storage (local oversupply).

The resulting cost is minimised through a Distributed Constrained algorithm on the sub-tree rooted by the controller on the node equipped with a storage.

Generation of electricity

In a further embodiment, the user facility may include any photovoltaic (PV) device of which the technology is based on conversion of solar radiation to electrical power such as solar panels for generation of electrical energy. It serves as a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or at so-called solar parks. The latter generate merely electrical energy that is fed into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the PV devices at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In case of heavy load on the utility grid the generation devices can feed it taking into consideration the information of its voltage magnitude and its frequency. Otherwise, their energy is buffered in the storage devices up to the full state of charge.

In a further embodiment, the user facility may include any form of wind turbines that convert wind energy into electrical energy for generation of electrical energy. It serves as a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or at so-called wind parks. The latter generate merely electrical energy that is fed into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by wind turbines at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility or fed into the utility grid in function of the needs.

In a further embodiment, the user facility may include any form of hydro power that converts potential or kinetic energy of water into electrical energy for generation of electrical energy. It serves as a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or at so-called hydro power stations. The latter generate merely electrical energy that is fed into the utility grid to satisfy demands at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the hydro power plant at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

In a further embodiment, the user facility may include any form of device that converts the chemical energy from a fuel into electricity for generation of electrical energy. It serves as a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter generate merely electrical energy that is fed into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the chemical fuel-fed device at the user facility serves to satisfy local the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

In a further embodiment, the user facility may include Diesel/gasoline and rotary engines that generate mechanical and thermal energy. The mechanical energy may be converted into electricity for the generation of electrical energy. The thermal energy can be used for heating the facility. Fed with bio fuels it serves as a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the Diesel/gasoline and rotary engines at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

In a further embodiment, the user facility may include Stirling engines that generate mechanical and thermal energy. The mechanical energy may be converted into electricity for the generation of electrical energy. Heat supplied to the Stirling engine from renewable sources makes it a renewable energy device to generate electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the Stirling engines at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

In a further embodiment, the user facility may include turbines with arbitrary working fluids that generate mechanical and thermal energy. The mechanical energy may be converted into electricity for generation of electrical energy. Heat supplied to the turbines from renewable sources makes it a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices. The electrical energy generated by the turbines at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

In a further embodiment, the user facility may include electrolysis devices that convert any kind of fluids into gas that can be burnt in combustion engines to generate mechanical and thermal energy. The mechanical energy may be converted into electricity for generation of electrical energy. Heat supplied to the turbines from renewable sources makes it a renewable device to generate electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid to satisfy the demand at the user facilities that are temporarily not met neither by the generation nor the storage devices. The electrical energy generated by the engines at the user facility serves to satisfy the local demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the utility grid or buffered in the storage devices.

Generation of thermal energy

In a further embodiment, the user facility may include any kind of heat pumps that convert energy on a low temperature level to energy on a higher temperature level. It serves as a renewable device to generate thermal energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds heat into a network to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices of thermal energy. The thermal energy generated by heat pumps at the user facility serves to satisfy the local demand for thermal energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the heating network or buffered in the storage devices.

In a further embodiment, the user facility may include any kind of solar thermal panels that converts solar radiation into heat. It serves as a renewable device to generate thermal energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds heat into a network to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices of thermal energy. The thermal energy generated by the solar thermal panels at the user facility serves to satisfy local the demand for energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the heating network or buffered in the storage devices.

In a further embodiment, the user facility may include any kind of fermenter that converts organic residues into gases to produce electricity by mechanical devices such as a combustion engine with a generator or thermal energy by combustion. It serves as a renewable device to generate thermal or electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid or heat into a network to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices of electrical and/or thermal energy. Gases produced by a fermenter at the user facility serves to satisfy the local demand for electricity and thermal energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the electrical or heating network or buffered in the storage devices.

In a further embodiment, the user facility may include any kind of gasification device that converts renewable fuel in an under-stoichiometric environment at any temperature into gases to produce electricity by mechanical devices such as a combustion engine with a generator or thermal energy by combustion. It serves as a renewable device to generate thermal or electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid or heat into a network to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices of electrical or thermal energy. Gases produced by gasification at the user facility serve to satisfy the local demand for electricity and thermal energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the electrical or heating network or buffered in the storage devices.

In a further embodiment, the user facility may include any kind of pyrolysis device that converts renewable fuel in an oxygen-free or low oxygen environment into gases to produce electricity by mechanical devices such as a combustion engine with a generator or thermal energy by combustion. It serves as a renewable device to generate thermal or electrical energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds electricity into the utility grid or heat into a network to satisfy the demand at the user facilities that are temporarily not met neither by generation nor storage devices of electrical or thermal energy. The gases produced by pyrolysis at the user facility serve to satisfy the local demand for electricity and thermal energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the electrical or heating network or buffered in the storage devices.

In a further embodiment, the user facility may include any kind of incineration or combustion device that oxidises renewable fuel to produce thermal energy. It serves as a renewable device to generate thermal energy and may be installed locally at the premises of the user facility or in larger units. The latter feeds heat into a network to satisfy demands at the user facilities that are temporarily not met neither by generation nor storage devices of thermal energy. The gases produced by combustion at the user facility serve to satisfy the local demand for electricity and thermal energy or in case of a surplus of energy it is stored at the user facility. In function of the needs the energy can be fed into the heating network or buffered in the storage devices.

Storage of electricity, mechanical and thermal energy

In a further embodiment, the user facility may include any kind of batteries that store and release electrical energy. Batteries are charged either by local devices installed at the user facility or by the utility grid. The stored energy of batteries is utilised to supply power under circumstances when the consumption at the user facility exceeds the capacity of the generation devices of electricity.

In a further embodiment, the user facility may include any kind of super capacitors that store and release electrical energy at high rates. The super capacitors are charged either by local devices installed at the user facility or by the utility grid. The stored energy of the super capacitors is utilised to supply power under circumstances when consumption at the user facility exceeds the capacity of the generation devices of electricity.

In a further embodiment, the user facility may include any kind of mechanical devices such as a flywheel that store and release mechanical energy. Devices to store mechanical energy are charged either by local devices installed at the user facility or by the utility grid. The stored energy of these devices is utilised to supply power under circumstances when the consumption at the user facility exceeds the capacity of the generation devices of electricity or may be converted into electricity to be fed into the utility grid.

In a further embodiment, the user facility may include any kind of arbitrary working fluids that are pressurised in a tank to store and release mechanical energy. Arbitrary working fluids are pressurised at the user facility by local devices such as compressors at larger decentralised units. The stored mechanical energy of arbitrary working fluids is converted into mechanical energy by any kind of machine based on the principle of expansion. The released mechanical energy may be converted into electricity in a further conversion step. The pressurised arbitrary working fluids serve for storage and release of mechanical energy at high rates under circumstances when the consumption at the user facility exceeds the capacity of the generation devices of energy.

In a further embodiment, the user facility may include any kind of tanks filled with arbitrary working fluid to store and release thermal energy. The latter is stored by heating an arbitrary working fluid and released by cooling an arbitrary working fluid by heat exchangers installed at the user facility. The capacity of the stored thermal energy may cover the demand from a few hours to several months. Thermal energy stored at the user facility serves to satisfy the local demand or in case of a surplus of thermal energy it is fed into a network. Similarly thermal energy is received from the network to be stored at the user facility if the storage from the devices at the user facility is not sufficient.

In a further embodiment, the user facility may include any kind of tanks filled with arbitrary working material to store and release thermal energy based on the principle of latent heat e.g. employing latent heat that is stored or released during a phase change. The thermal energy is stored by heating an arbitrary working material and released by cooling an arbitrary working material by heat exchangers installed at the user facility. The capacity of the stored thermal energy may cover demands from a few hours to several months. The thermal energy stored at the user facility serves to satisfy the local demand or in case of a surplus of thermal energy it is fed into a network. Similarly thermal energy is received from the network to be stored at the user facility if the storage from the devices at the user facility is not sufficient.

A first prototype for a large scale application has been built-up and tested in the lab for electrical drives at the UL as shown in Fig 9. Fig 9 shows a Laboratory prototype of the present invention. A representative user facility 11 is equipped with user facility devices 911 to 914 for generation, storage and consumption of both electrical and thermal energy. The user facility 11 is connected to the present utility grid 3. Within the user facility 11 a controllable switch 935 connects the user facility 11 to the utility grid 3. Each of the user facility devices 911 to 914 is connectable to the switched branch of the utility grid by a dedicated switch 931 to 934.

Within the user facility 11, a user facility control unit 920 is connected to the utility grid control unit 20 via a user facility control link 21. Each of the switches 931 to 935 is connected to the user facility control unit 920 via a dedicated user device control link 921 to 925.

In the example illustrated in Fig 9, the user facility devices are arranged as follows: externally controllable inverter 911 for a storage battery pack 941, externally controllable inverter 912 for photovoltaic power panels 942, uncontrolled electric energy consumers 913, hydro turbine and pumping storage 614.

The externally controllable inverters 911 and 912 are each provided with a user device transceiver 951 and 952. A utility coordinator 998 is connected to a coordinator transceiver 999, such that via communication links 991 and 992 it can control the externally controllable inverters 911 and 912.

The results have shown that the different power units can be synchronised together and the electrical power flow between the units together as well as between the units and the grid can be controlled independently and accurately. A grid-tied as well as a stand-alone operation mode of the power devices is carried-out with respect to the electrical power quality specified by the European Norm EN 50160.

CLAIMS

1. A method of communicating operation modes between a user facility control unit at a user facility and a utility grid control unit of a utility grid, the method comprising the steps of:

   providing a utility grid;

   providing at least one centralised grid control means for controlling the utility grid in at least one utility grid operation mode;

   providing at least one user facility;

   providing at least one user facility control means for controlling the at least one user facility in at least one user facility operation mode;

   providing communication means for communication between the at least one centralised control means and the at least one user facility control means;

   communicating, from the at least one utility grid control means to the at least one user facility control means, a utility grid operation mode; and

   communicating, from the at least one user facility control means to the at least one utility grid control means, a local operation mode;

2. The method of claim 1, wherein the step of communicating a user facility operation mode comprises communicating information relating to energy generators in conjunction with the distribution of energy and the consumers.

3. The method of any one of the preceding claims, wherein the step of controlling the utility grid comprises a method of self-learning, optionally based on neuronal networks or fuzzy logic.

4. The method of any one of the preceding claims, wherein the step of controlling the at least one user facility comprises a step of self-learning, optionally based on neuronal networks or fuzzy logic.

5. The method of claim 4, wherein the step of self-learning comprises creating a user facility profile by monitoring a consumption behaviour of the user facility at least during an initial consumption learning period.

6. The method of claim 7, wherein the consumption learning period extends from one day up to as long as a year.

7. The method of any one of claims 4 or 5, wherein the step of self-learning comprises creating a user facility profile by monitoring an electrical and/or thermal energy behaviour of the user facility at least during a generation learning period.

8. The method of claim 7, wherein the generation learning period extends from one day up to as long as a year.

9. The method of any one of claims 4 to 8, further comprising the step of anticipating, based on the user facility profile, demands and needs for energy generation, energy storage and energy consumption at the user facility.

10. The method of any one of the preceding claims, wherein the at least one user facility comprises at least one generator and/or consumer, and the communication method further comprises providing a logical tree structure comprising at least one generator and/or consumer.

11. The method of claim 10, wherein the step of controlling the at least one user facility further comprises monitoring an operation status of the at least one generator and/or consumer and determining, based on the status, whether the at least one generator and/or consumer shall be connected to the utility grid.

12. The method of any one of the preceding claims, wherein the step of communicating comprises communicating over a local or wide area network, optionally based on Ethernet communication, powerline communication, or wireless communication.

13. The method of any one of the preceding claims, wherein the step of controlling the at least one user facility further comprises, in case of communication loss, controlling the user facility in a droop controlled mode derived from the frequency and/or the voltage deviation of the utility grid.

14. The method of any one of the preceding claims, wherein the step of communicating comprises admitting a new participant to a local sub-tree in response to a request received from the new participant and in response to an authorisation received from the first user facility controller node to answer this request.

15. The method of claim 14, comprising authentication by a symmetric key scheme, with the key incorporated into the communication.

16. The method of claim 15, wherein this key is further used to encrypt the data transfer, on the controller platform used.

17. The method of any one of the preceding claims, wherein the robustness of the communication network is ensured by dynamic reconfiguration of the participants in case of a lost link, i.e., the ability to reconnect by selection of a new router.

18. The method of any one of the preceding claims, wherein the role of the gateway to the distribution power grid can thus be reassigned to other suitable nodes ensuring redundancy in the cross connection.

19. The method of any one of the preceding claims, wherein the user facility profile comprises data given by measuring the power produced by the user facility's power units, the power consumed locally at the user facility, the power supplied into the utility grid, the energy produced and consumed at the user facility, the incomes at the user facility related to the energy sold, as well as meteorological data and the method comprises the step of storing this data over the time on a storage device.

20. A user facility comprising a user facility control means, the user facility control means comprising communication means for communicating operation modes to and from a utility grid control unit of a utility grid, the user facility control means comprising means for controlling the at least one user facility in one of a plurality of predefined operation modes;

the at least one user facility control means comprising means for receiving, from the at least one utility grid control means, a utility grid operation mode and further comprising means for operating the at least one user facility in a received operation mode;

the at least one user facility control means comprising means for detecting a local operation mode an further comprising means for communicating the detected local operation mode to the at least one utility grid control means.

Abstract

A method of communicating operation modes between a user facility control unit at a user facility and a utility grid control unit of a utility grid. The method comprises the steps of: providing a utility grid; providing at least one centralised grid control means for controlling the utility grid in at least one utility grid operation mode; providing at least one user facility; providing at least one user facility control means for controlling the at least one user facility in at least one user facility operation mode; providing communication means for communication between the at least one centralised control means and the at least one user facility control means; communicating, from the at least one utility grid control means to the at least one user facility control means, a utility grid operation mode; and communicating, from the at least one user facility control means to the at least one utility grid control means, a local operation mode.

(Fig. 1)

RUES004

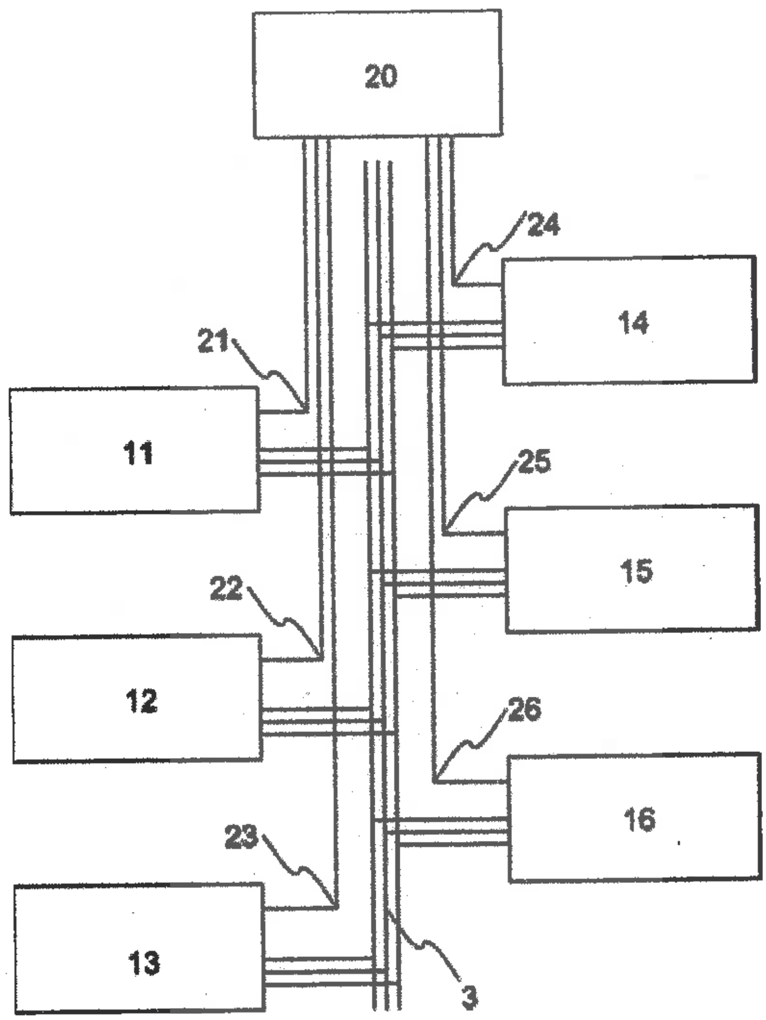
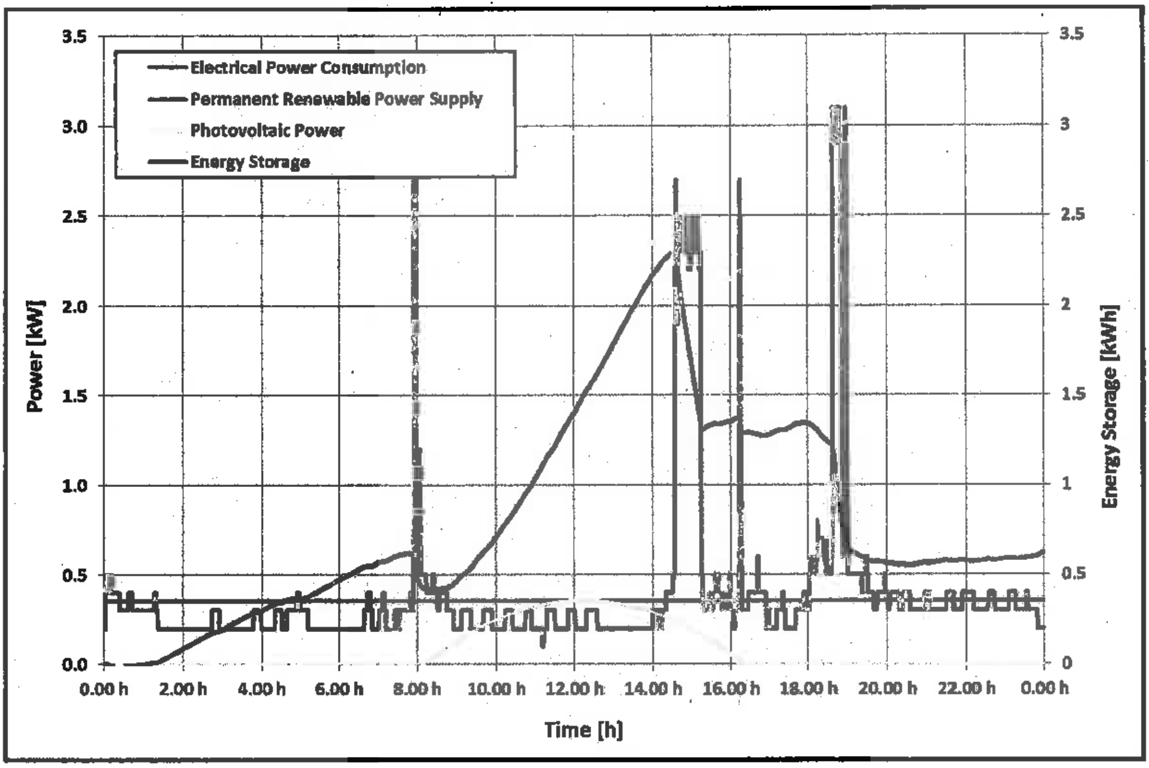


Fig. 1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Photovoltaic Power
Energy Storage
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Energy Storage [kWh]

Fig. 2

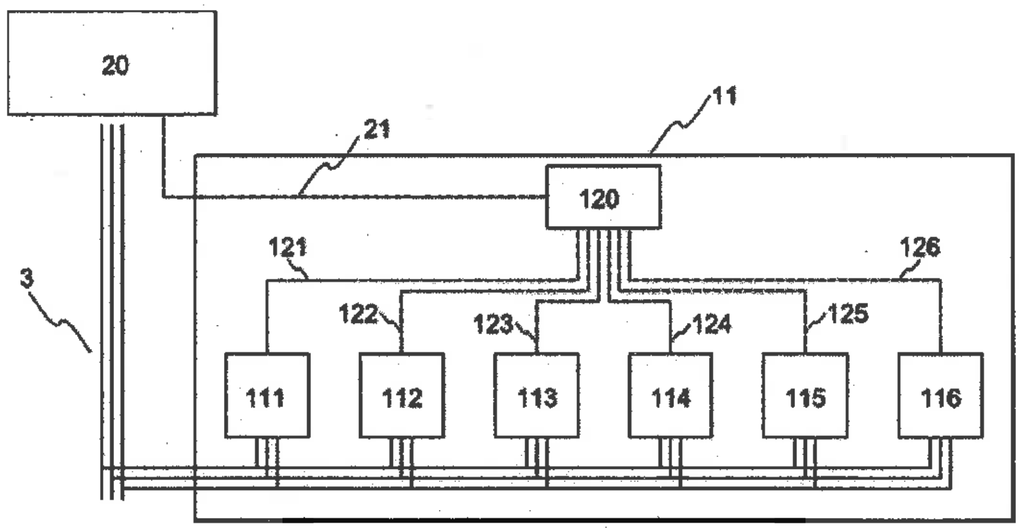
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Fig. 3

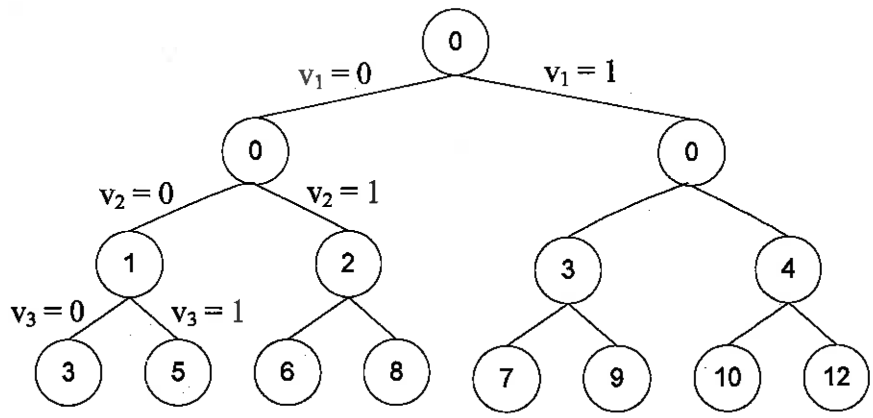

Fig. 4

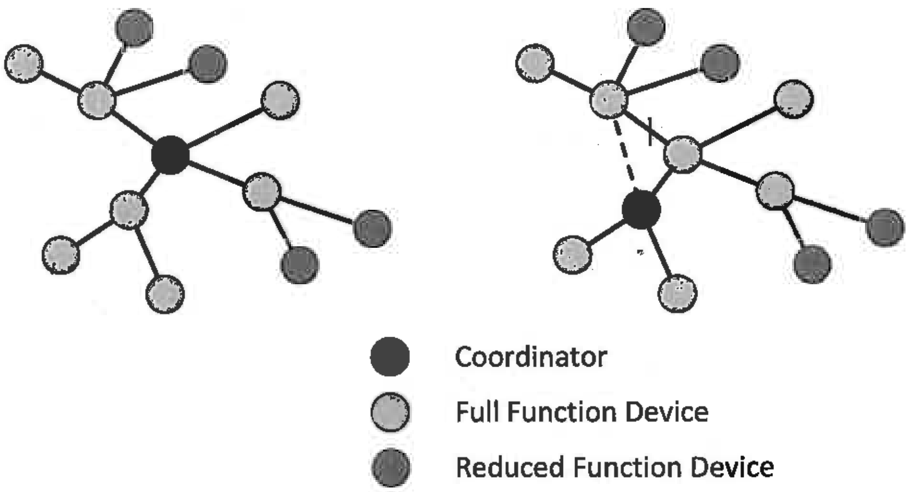

Fig. 5a

Fig. 5b

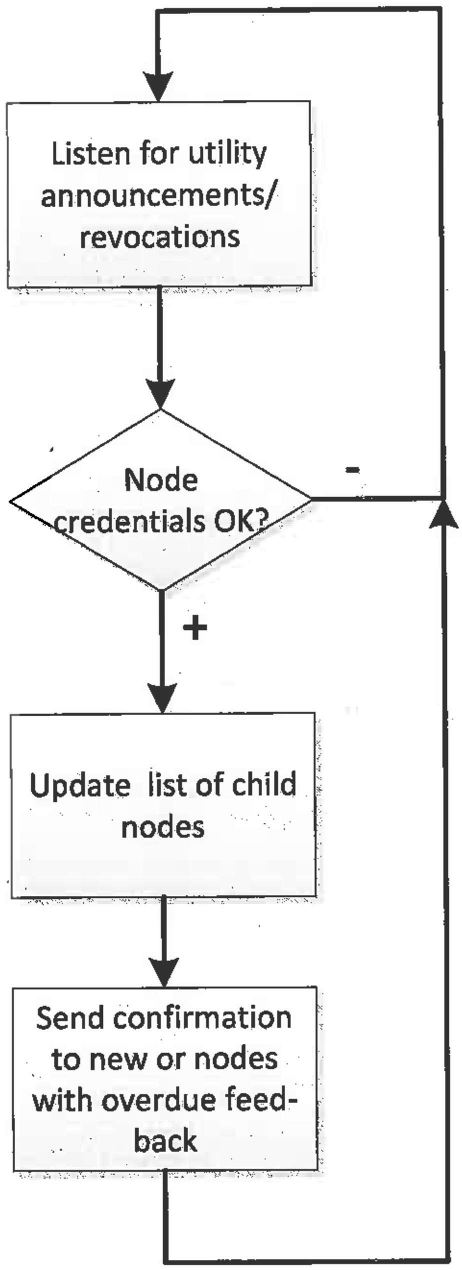
Listen for utility announcements/ revocations
Node credentials OK?
-
+
Update list of child nodes
Send confirmation to new or nodes with overdue feed-back

Fig. 6

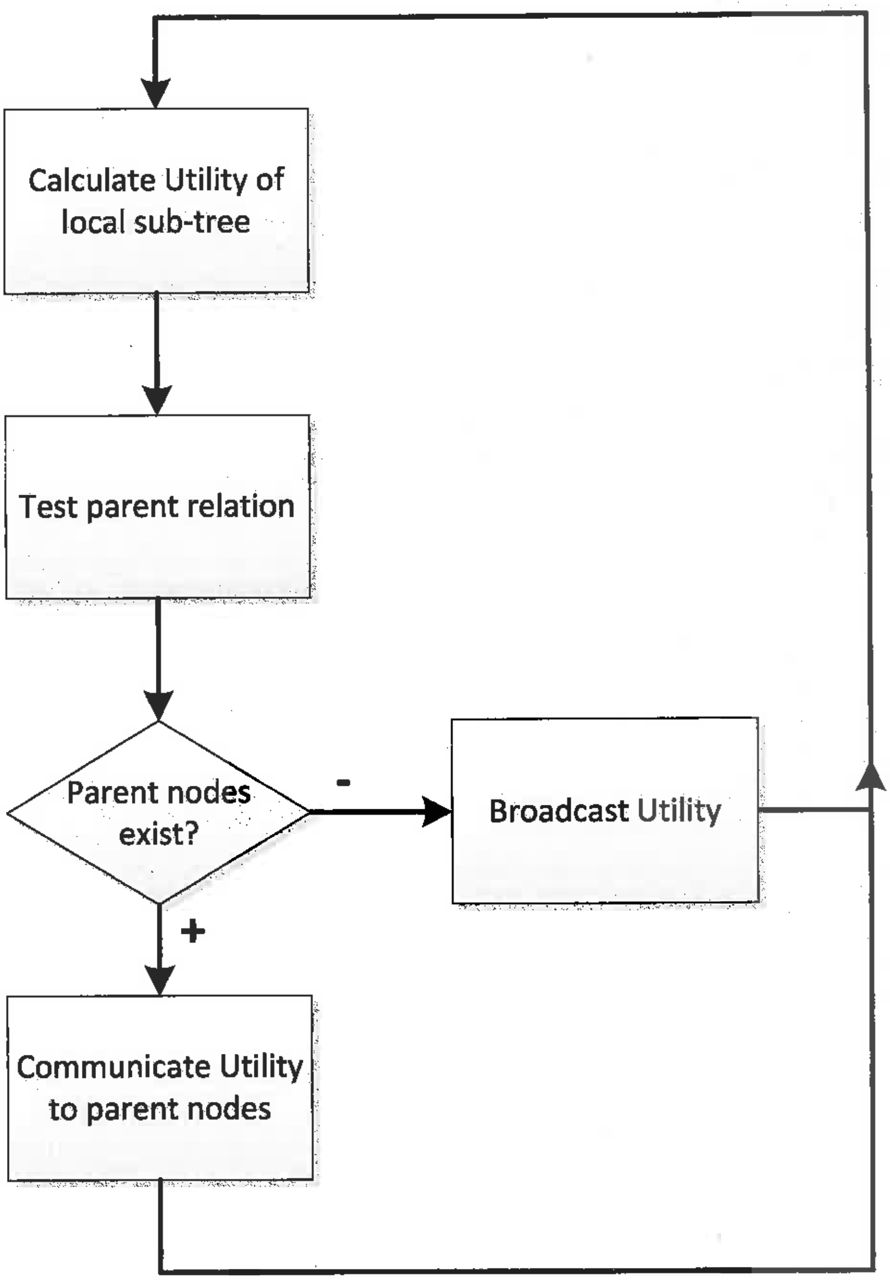
Calculate Utility of local sub-tree
Test parent relation
Parent nodes exist?
-
Broadcast Utility
+
Communicate Utility to parent nodes

Fig. 7

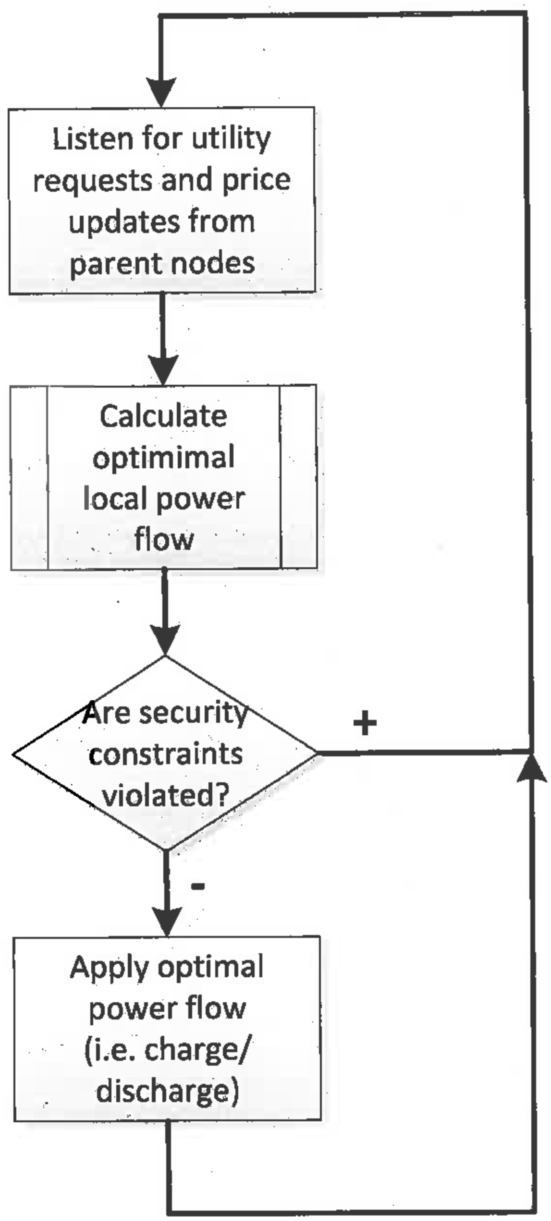
Listen for utility requests and price updates from parent nodes
Calculate optimimal local power flow
Are security constraints violated?
+
-
Apply optimal power flow (i.e. charge/ discharge)

Fig. 8

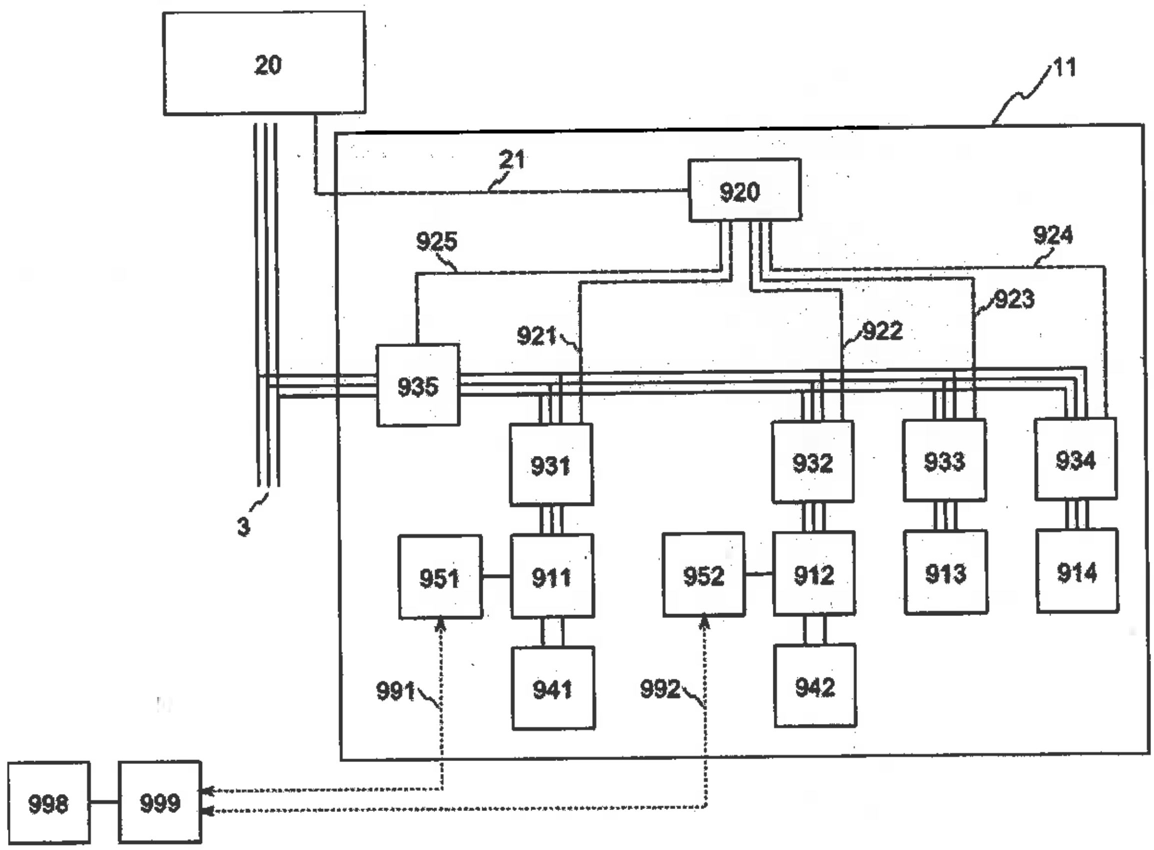
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Fig. 9