Abstract — One of the EU energy policy goals is development of utilization of renewable and small local power sources. Local balancing of power production and consumption is aimed due to power transmission losses minimization. In other words all energy consumed in separated small area (cottage, town and commune) should be produced within this area. Research it has been done so far shows that it is very hard, in particular using unstable renewable power based on solar and wind energy, to reach the aim with keeping very high quality factors, high efficiency and low costs. Renewables like solar and sun energy have many disadvantages. To avoid these disadvantages sources are connected together into hybrid systems. The hybrid systems can be realized as AC or DC current. An idea of DC current solution is presented in the paper. In authors opinion such system using power electronics converters and advanced control systems allows easier effective connection of different power sources as AC current. In particular there are no problems like reactive power control, voltage and current distortion, reactive loses etc.

Index Terms — distributed generation, renewable power sources, micro grids, power electronic converter

I. INTRODUCTION

Strategic aims of EU clearly describe the role of distributed generation (DG) and renewable energy resources (RES) in power production. Experts are unanimous that DG participation in production will be rising also due to economical reasons. Unfortunately it will cause necessity of some changes in power system. Current centralized solutions have to be transformed [6]. The transformation is forced by another EU aim – power quality rising.

From opposite direction EU main goal is sustainable development. In case of power it means increasing of efficiency, RES utilization and local energy balancing.

Local balancing means that almost all energy consumed in separated area needs to be produced within this area using local primary carriers. Such solution allows to minimize power loses connected with power transmission and power distribution and encourages investment in local small production units.

Goals and development directions described above require transformation of current distribution networks of medium and low voltage. It is necessary to introduce possibility of local control of power flow. Protection systems need to work with bidirectional energy flows. There is no data communication subsystem necessary to control all components in current distribution network. In consequence the idea of hybrid systems and micro grids was come into being. Micro grid means small, balanced power subsystem which connects distributed power stations and consumers located on not big area. Description of different AC micro grids can be found in [5][7].

Unfortunately, a disadvantage of AC systems is problem of voltage and frequency control (reactive and active power flow). It is clear that there will also problems with voltage distortion due to wide utilization of power electronic converters.

Authors propose to use DC current hybrid systems as a solution which avoids most of problems described above. The solution allows keeping low costs in many cases and makes easier some issues connected with control of quality parameters. Problem of quality in DC systems is reduced to keep voltage or current in required range.

II. HYBRID PRODUCTION SYSTEM

DG production systems operate currently as connected to public grid or stand alone units. Depending on the connection they have different tasks and need to meet different technical and economical requirements.

In case of grid connected units, they fulfil one of goals mentioned below:
• improvement of power reliability,
• improvement of economical parameters of power supply,
• yield a profit from power sale.

Such production systems are designed as single units or composed of a few equal units connected in parallel. They are fuelled by cheap and easy to reach primary energy carriers like natural gas and fuel oil. These type units have mostly very good technical and economical parameters and they allow achieving assumed investment goals.

The units designed as stand alone have different tasks. Their most common goal to supply loads which
cannot be connected to public grid for various reasons. In case of stand alone units, there are the most important such technical parameters as reliability and availability factors. Various primary carriers are utilized in the stand alone systems. Renewable power sources, like solar radiation and wind, have found applications in the systems located in hard to reach places. Development of the systems has begun from at least seventies. There were mainly designed the systems for telecommunications. Hence, availability and reliability were particularly important. A necessity to double power sources and to utilize different primary carriers in order sources had to reduce their disadvantages each other. Hybrid power production systems, called also hybrid power plants, have come into being in that way. The most common were hybrids like sun and diesel, wind and diesel, sun and wind, sun, wind and diesel.

Hence, hybrid power plant can be defined as production system consists of at least two power production units utilizing various primary carriers. Primary power and conversion equipment need to be designed in this way that the plant have significantly better technical (mainly reliability and availability) and economical (energy production const) performance then each of the sources separately in the light of investment aim.

Hybrid systems are utilized broader range then in seventies. They are also connected to public grid. It is involved with new goals in power engineering and DG:

- broad utilization of renewable power sources,
- local primary resources utilization,
- local energy balancing.

The characteristic feature of the hybrid plants is interconnection between power converters by means of control systems. The control systems’ task is control of power production process in order to remain assumed technical and economical parameters. The basic problem is division of load among sources that produced energy is as cheap as it is possible and/or the sources operate at optimal points.

From technical point of view, hybrid power plants consist of power production units, control system, power balancing point and output equipment. Power balancing often takes place in AC line which the plant and loads (including power grid) are connected.

Authors propose the system in which power is balanced in special DC current circuit. And loads will be connected via power electronic inverters (fig. 1).

Classic hybrid plant is designed as concentrated device. All components are located close to each other. So impedances of interconnections can be neglected and load is joined at one point.

New type of hybrid systems called micro grids is under developing at present. Then production units are laid out in space, even on significantly large area. Impedances of connections between sources are so large in such system that they cannot be neglected. Loads can be joined at several points also between sources. In particular number of possible combinations of sources and loads connections is infinite. In practice it is limited by site, technical and economical conditions. Construction of control system becomes particularly difficult. An open and distributed structure of control system needs to be applied. The problem is still under development.

Fig. 1. Authors’ proposition of distributed DC current hybrid system.

III. HYBRID DC CURRENT POWER PRODUCTION SYSTEM

The DC current hybrid power plant proposed by authors originates from telecommunications power supply systems, where load is supply just by DC current. Such plant idea can be successfully transferred to power engineering. The principle of operation of the plant bases on assumption that all sources produce DC current and loads are joined by inverters. In fact, the modern technology of cheap inverters allows broad introduction of DC systems into power engineering.

Power balancing takes place in DC circuit. In consequence, control of energy flow simplifies from multi-dimensional problem (amplitude, frequency, phase and shape control) into one-dimensional – voltage level control at given point (fig. 2). The problem of preservation of energy quality factors simplifies to voltage level control on inverter’s input as well. All control systems and algorithms became much simpler and costs are reduced.

Fig. 2. Power control is equal to voltage control in DC system.

DC current systems also can be constructed as concentrated or distributed. The example of the concentrated plant is shown in fig. 3 and distributed in fig. 4.
At the first moment, it could seem that introducing of DC circuit causes increase of number of power electronic converters. In fact, most of modern power sources have intermediate DC current circuit. So, total number of power transformations remains constant. Power transfer via DC link is often mentioned as future solution even in low voltage systems.

DC current sources connection allows avoiding an inconvenient process of AC sources synchronization and energy flow control between each other. Most of DC/DC converters are or can be easy made one-directional (diode in series). Nevertheless, bi-directional converters need to be applied as well (interconnection with public grid, battery storage systems etc.).

Consumers’ connection by inverters seems to be a disadvantage and superfluous system complication. But it has also some advantages. Each consumer can be connected individually or categorization can be introduced (fig. 5). First of all, it allows separating by DC link consumers who take distorted current. Next group can be consumers who are uncontrolled producers from time to time. Such consumers need to be joined individually by bi-directional converters.

### IV. Power Electronics Converters

Power electronics converters function as:
- voltage type and level adapters,
- primary energy converters’ controllers in power systems.

The other function is galvanic isolation particularly in DC circuits.

Primary energy into effective electric energy converters (popularly called power sources) can be divided into a few groups from type of produced voltage point of view:
- AC current sources with stable frequency and voltage level,
- AC current sources with variable frequency and voltage level,
- controllable DC current sources,
- uncontrollable DC current sources.

Each type of source requires special kind of power converter, one- or multistage. Multistage converter is applied if one cannot meet all requirements from source and load points of view.

AC current sources first of all are diesel or gas engine gensets and gas turbine at present. The sources are adapted to operate stand alone. Thus they generate sinusoidal voltage wave with constant parameters in wide range of load. A converter applied to such source consists of two stages – rectifier and voltage matching converter (fig. 6). Rectifier can be simple diode bridge or controllable rectifier taking sinusoidal current. Choice of proper rectifier depends on generator power and ability to work with nonlinear load.

AC current sources generating sinusoidal or not voltage waves with variable frequency and amplitude are synchronous generators, often with permanent magnets, slow or high speed. The generators are used in such sources like modern high frequency diesel gensets, wind turbines etc. The sources work with converters consists of rectifier and voltage matching converter. (fig
7). Due to possible frequency changes these are simple diode bridges.

Fig. 7. Converter for variable speed generators.

The most common DC voltage sources are chemical batteries, fuel cells and solar batteries at present. All have soft voltage-current profiles, partially similar to ideal voltage source or current source. So, generated voltage changes due to load changes. It is necessary to use at least one stage converter – voltage matching – in most of applications (8).

Fig. 8. Converter for constant DC sources.

Some sources can be controlled from output. Working point can be changed by load current control. The best example of such source is solar battery. Then two converters need to be applied, first for working point control, second for voltage matching. (fig. 9).

Fig. 9. Converter for DC controlled sources speed generators.

Discussed converters can be applied in huge range of power at present. If transmitted power exceeds level of megawatts, multipulse thyristor rectifiers and inverters need to be taken into consideration, particularly in case of public grid connection. Thyristor converters in range of power above megawatts are significantly cheaper at present.

V. CONTROL SYSTEM FOR HYBRID POWER PLANTS

As it is discussed in [1][5][6], hybrid power plants need to have special controllers to optimal power production, resources utilization and cost reduction. Control strategy consists in assignment required power level at the moment to all sources. The level of power is calculated as a function of the current plant state, energy resources state and technical and economical limitations of all sources together and individually. For instance, in case of the hybrid power plant consists on solar battery and fuel cell, fuel cell should be switched off during beautiful sunny day, kept as hot reserve during cloudy day and operate in winter dark day.

Determination of optimal or suboptimal generation level for all sources is not easy. Particularly in case of changing loads. It need to be remembered that power resources’ estimation could be hard as well as power flow from or to power grid. An ideal solution would be if the hybrid system could be seen as planned source or load.

Power converters designed by authors are equipped with automated control systems [3] which allows, beside to set produced power level, to measure all important quantities and to control device state. It also allows detecting beforehand some failures. The system is modular and is able to communicate with environment using one of the popular interfaces. It is possible to communicate by Internet, GSM or RS 485 protocols.

VI. AN EXAMPLE OF HYBRID PLANT

Authors have built a simple DC hybrid power plant. The plant consists of fuel cell and solar battery. The plant was developed to supply stand alone load. The aim of the experiment was to find if assumed control strategy of power sources works well and because of that if the technical aim – high power reliability and availability – is reached. Particularly it was interested if it is possible to avoid disadvantages of solar batteries and to reach availability close to 100%. An effect is model of the hybrid power plant shown in fig. 10 – solar source, and 11 – fuel cell.

Fig. 10. Solar batteries – a part of authors’ DC hybrid system.

Fig. 11. Fuel cell – a part of authors’ DC hybrid system.

The principle of operation of the plant is the solar energy is cheapest so solar battery should supply load as long as it is possible. Especially when there is not enough solar power to cover demand and it have to re-
plenished by fuel cell.

The power electronic converters were designed (fig. 12). The control algorithm was implemented. Simulation and practical experiments were done. Some results are shown in fig. 13 and 14.

Fig. 13 shows sunrise. It could be seen that current produced by solar source rises with time and fuel cell current falls down. The load current remains constant. The same could be seen at fig. 14. The curves were registered during cloudy November day.

![Fig. 12. Converters of authors’ plant: DC/DC1_A – solar batteries control converter, DC/DC1_B – solar batteries voltage matching converter, DC/DC2 – fuel cell voltage matching batteries.](image)

![Fig. 13. Currents generated during sunrise.](image)

![Fig. 14. Power generated by solar source and fuel cell during cloudy November day.](image)

**VII. SOME ECONOMICAL ASPECTS**

The aim of such investment as hybrid power plant is to reach performance unattainable for single generation units. First of all it is power investment so it needs to yield a profit. Therefore the investment needs to be analysed due to production profitability. However it is placed emphasis on other benefits as renewable sources or local resources utilization. The research aim is to find technical solution which allows yielding a profit in future market conditions. Authors’ research focuses on determining which costs have the strongest impact on total price of power generation and how to develop the system configuration, sources’ power and control strategies in order to price minimization. It has been considered which future conditions have the strongest impacts. Each technical project designed by authors is analysed in this way. The goal is to find the best solution from both technical and economical points of view.

One of the possible methods of costs analysing is UNIPEDE method (1). It allows comparing variants from the point of view of generation costs and regardless of sale’s results.

\[
K_j = \frac{I_0 + \sum_{i=1}^{N} KU_i + A_k p_i}{\sum_{i=1}^{N} P_i T_i} (1 + p)^j
\]

The research has been done for example of the hybrid power plant described above. Such aspects were considered as:
- validity of two sources power plant,
- selection of power of each source,
- influence of selected costs entries (i.e. hydrogen and solar panels prices),
- sources’ lifetime influence.

Two variants were considered – without any special control algorithm (case W1) and with authors’ control strategy (case W2).

It turned out that the most important are fuel cell lifetime (fig. 15), fuel cell price (fig. 16) and number of installed solar panels (fig. 17) [2]. All results are related to base total cost of power:

\[
K_{jd0} = 6.15 \, \text{€/kW·h.}
\]

![Fig. 15. Fuel cell lifetime influence on power cost.](image)
The hybrid system allows reaching the technical goal – high availability and reliability. Cost analyse shows that generation costs are also lower.

VIII. CONCLUSIONS

Hybrid systems allow constructing generation units which have not many disadvantages of generation units based on unstable, unpredictable or periodic energy sources like sun radiation, wind and water. The fossil fuels utilization can be reduced. Unfortunately, these are still much more expensive solutions than classic at present. But taking into consideration today’s fluctuation of oil price it is clear that their time has coming very fast. Thus intensive research is necessary in order to be prepared to mass introduction of different power sources in the near future.

Common utilization of small power units, often unstable and unpredictable, will be causing necessity of build networks subsystems called micro grids or hybrid generation system. Micro grids, according to EU strategic goals, will cover all energy demand in area they will be built using local primary carriers. It is political aim which has to be realized. It will increase power safety and life level by increasing of power availability, efficiency and quality.

Intensive research is performed on micro grids all over Europe. Authors propose, as their own contribution, DC current hybrid system or micro grid. The DC systems have some advantages including:

- avoiding many difficulties with control of energy parameters,
- simplification of control strategy and units,
- costs reduction,
- developing of new method of energy measurement.

Presented results of authors’ research have shown that relatively simple system can realize advanced algorithms. Thus technical realization of the DC micro grid is possible and quite simple at present time, but some development is still necessary for further improvement of economical and technical properties. Present sudden development of power electronic converters and data communication equipment and significant their costs reduction goes towards broad utilization of DG hybrid systems.

REFERENCES