IMPLEMENTATION OF NANOGRIDS FOR FUTURE POWER SYSTEM

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ABSTRACT: *Microgrid is a new technology in power generation and this system is used to provide power and heat to its local area, such as cogeneration systems and renewable energy (wind turbines, photovoltaic cells, etc.). They are preferred for medium or high power applications. Nanogrid most likely to be used in small local loads for rural area as they will be more economic then the normal grid power system. Nano grids can operate independently or be connected to the mains and most likely the internal voltage can be utilized as ac or dc. In this research paper a small scale microgrid system is proposed for smart homes called "Nanogrid". Each houses have small electrical power system from them can be shared among houses. If it uses a DC system instead of a general AC system, it can reduce energy loss of inverter because each generator doesn't need an inverter. Furthermore, it can continue to provide a power supply when blackout occurs in the bulk power system. A model of a nanogrid is developed to simulate the operation of the centralized power control. Finally a Simulink model is presented for small houses power range 90-285 KW.*

Key words: *Nanogrid, microgrid, cogeneration, energy storage, nanotechnology, centralized power system*

I. INTRODUCTION

In recent years, various energy systems to share heat or electric power have been proposed to improve the energy efficiency and operation ratio of cogeneration systems. Some systems use hydrogen from outside shared reformers as fuel for cogeneration system. Electrical power distribution system is shown in Figure 1.

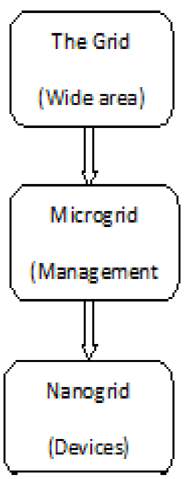


Figure 1: Power Distribution System

The main grid consists of wide area and microgrid cover medium area and utilizes the alternative energy resources. The Nanogrids consists of devices and used its own power system such as PV solar cell and heating system.

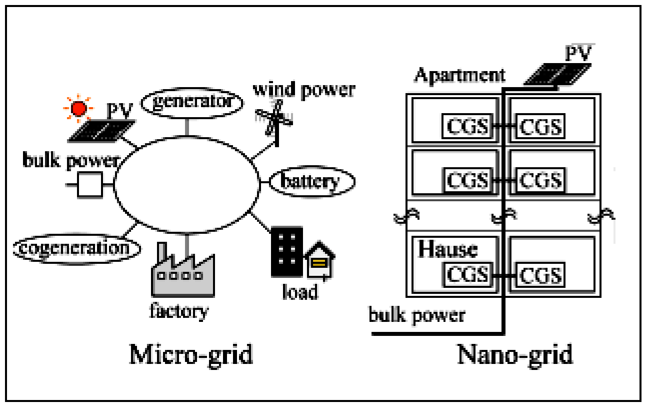
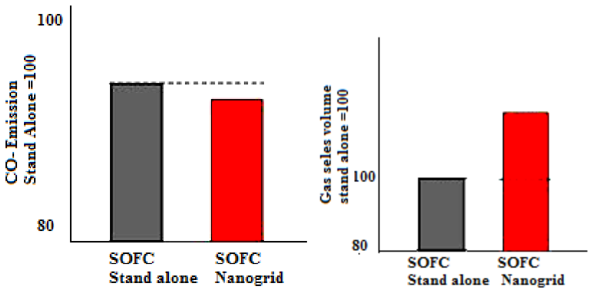


Figure 2: Microgrid and Nanogrid System [1]

The microgrid systems are the focus of research all over the world the sharing of electronic power and heat (CHP) system. The microgrid system consists of distributed generators such as cogeneration systems and renewable energy systems (wind turbines, photovoltaic cells, fuel cell etc.). The concept of Nano-grid is that at small scale we select houses around 50-150 houses and the each house has its own PV cells or a fuel cell cogeneration system as shown in figure 2. The outputs of all distributed system of generations are connected to the distribution line, and the electrical power can be borrowed and lent among houses through the distribution line. In future use of CHP System will be increased and cogeneration system will used in each house. For operators to keep the system efficiency high the generators at distribution side should not be lightly loading and operates should use a start/stop control. CO_2 emission effect would reduce because each house uses a hot water. The Gas Seles Volume is shown in case of using SOFC (Figure 3.a and b).



(a) (b)

Figure 3: Advantage of "Nano-grid" with SOFC.

A Nano-grid uses a DC system instead of a general AC system, it can minimize use of the inverter because each generator doesn't need an inverter. Furthermore, it can continue to provide a power supply when a blackout occurs in the bulk power system. In developing countries, there is a feature for nanogrid most likely to be used in small local loads of rural area as they will be more economic than the normal grid power system. Nano grids can operate independently or be connected to the mains and most likely the internal voltage can be utilized as DC.

II. ENERGY STORAGE DC NANO-GRID

In modern power system, role of energy storage has become even more important. Energy storage is necessary in micro-grid applications to ensure stability of the system in presence of bi-directional power flow of the micro-grid, alleviate the intermittency problem of small-scale renewable energy sources improve power quality, and support local generators for additional functionality such as peak shaving Load-shifting, frequency regulation etc.

For medium-scale and large-scale renewable energy plants, energy storage is necessary to improve controllability and reliability of the plants such that they can be integrated into power system without causing performance degradation of the system or requiring additional flexibility and operating reserves from the power system. DC technology In the ”War of Currents” in the late 1880s, AC current won over DC current due to its ease of step-up/down and ease of protection. However, there has been recently a return of DC technology [4] due to the presence of power electronics.

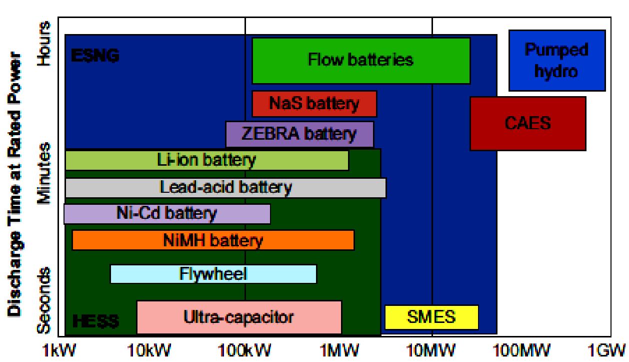


Figure 4: Energy Storage Systems

Table 1: Specification of Battery Technologies

Technology Available	Density of Power (Watt/Kg)	Energy Density (WHour/kg)	Life Cycle at 100% DOD and 25^0C	Charge/ Discharge Efficiency
Flooded lead acid	70-400	20-50	320-800	70-84%
VRLA	310	35-40	320-800	70-84%
Nickel Cadmium (Ni-Cd)	80-150	22-60	300-500	65-85%
Nickel Metal Hydride (Ni-MH)	120-300	35-95	600-1000	65-85%
Sodium Sulfur(Na-S)	75-230	75-240	2300-2500	75-83%
ZEBRA ($Na\text{-}NiCl_2$)	100-180	75-120	>1500	NA
Lithium-ion	100-1000	80-180	3000-5000	85-95%
Vanadium Redox	110	15-30	2800-3000	60-85%
Zinc Bromine	70-85	NA	1500-2500	60-73%

In figure 4 the different batteries with power discharging time are shown. Specifications of the batteries are given in Table.1. From table 1 it can be concluded that lithium- ion batteries are best candidate for future grid system because it has highest charging discharging efficiency.

III. ADVANTAGES OF NANOGRIDS

Followings are advantages of the Nanogrids

- Controllers discover other grids and generation system
- sharing power (price, quantity)
- Power can be exchanged mutually beneficial
- Controllers can track cumulative energy.
- Only data exchanged based on price and quantity
- Visibility of the systems adjacent grids
- Bring individual devices into grid context
- Pave way for Micrgrids
- Increase microgrid utility; enable local microgrid prices
- Reduce microgrid cost and complexity
- Can scale/deploy much faster than Micrgrids
- Enable “Direct DC” (~10% savings)
- Better integrate with mobile devices, mobile buildings
- Help bring good electricity services to developing countries
- It is more secure
- Coordinate only with immediately adjacent (directly attached) grids / devices
- No multi-hop “routing” of power

Table 2: Availability of Power Supply

Units to Supply Power	Fuel or Energy Source	Accessibility
Generator set with operation time less than two hours. Its fail to start probability is 0.0241	Diesel/Natural Gas	0.9939
Generator set with operation time greater than two hours. Its fail to start probability is 0.0241	Diesel/Natural Gas	0.85
PV Generation system	Solar Energy	0.996
PEM Fuel cell	Hydrogen/Natural Gas	0.967742
Micro turbines	Propane or Liquid Fuels or Natural Gas	0.993789
Wind Turbine	Wind	0.9595

VI. ISSUES RELATED TO THE POWER GENERATION AND CONTROL

The followings are the issues related to the power generation and control.

a. The energy storage will play important role in electrical power system. Physical size in the energy storage system play important role because more energy can be stored. If the size of a generator is greater than more output power is available in peak time. In smart grid system energy storage will play major role in energy generation side because grid will always use maximum stored energy to fulfill the demand of energy in the peak hours. By using the nanotechnology the energy storage system will store more energy to meet the demand.

b. The smart grid must control power generation system that can be varying instantaneously as load varies according to the requirement of the consumer. In future wind and solar energy system will be more and since these systems are depend on the weather conditions so the grid operator will need to take sudden actions as changes occurred in Power output [1].

c. The reliability of the grid depends on the synchronization between voltage and current**.** Since power equal to voltage multiply by current and since current fluctuations in an AC system and voltage has to fluctuate in the same way. Real or complex Power depends on the "Power factor," and it should be near to one. But typically it runs between 85-95%. If power factor reduce within the certain limits, it causes to lower the system fuel efficiency. It is happening because the generators will produce same amount of power by using the same amount of fuel but it will deliver less power to load and losses will be increased.

d. Complex power produce by capacitance and inductance and it generated from electrical equipments for example capacitors, tube lights and motors etc. These devices causes current to be out of phase with voltage and it should compensate, so power factor may vary in grid time to time and since this phenomena must happen due to presence of inductive type of load so operator needs to take necessary actions to improve the power factor up to the desired value.

e. Location is always play important role while calculating losses. The resistance of a wire depends on the length of the wire, as length increases the resistance of wire increases. Voltage is directly proportional to the resistance and current. Losses increase with distance and more wire is needed to provide electrical power to long distances. When more wire is needed to connect the generator with load, it reduces current and hence greater energy losses for any given voltage. The line losses should be minimized by impedance matching. These are between 3-5% on average. But these losses increase sharply during peak hours and often exceed up to 25% when wire are congested. Keeping in view above issues it can be concluded more fuel is required to generate the same amount of electrical energy and more money investment is required in the power generation system of any system with generators using in the remote site. These line losses will be reduce in future because researcher are improving transmission line wire by mixing Nanomaterials with copper wire.

f. In Pakistan electricity generation is very low and cost of electricity is very high as compared to the other developing countries. It totally depends on the centralized system. There is still no proper planning for future due to the influence of the arm forces around 35 years. This is big issue for country to fulfill the demand of electric supply and hence reduce the cost.

In future the decentralized system will be preferred because uses can use its own system in case of blackout. The cost of the energy can be controlled if different options are available.

V. PROPOSED SOLUTION FOR POWER CONTROL

This paper has presented a centralized control strategy for nano grid that allows micro-sources in a DC nanogrid. The control strategy is implemented by limiting the output current of micro-source interface at its maximum power. A model of a nanogrid is developed to simulate the operation of the centralized power control. The output power 90 kW generated by using PV Solar cell. To provide a high-power, high-flexible energy storage solution for applications of micro-grid and renewable energy plant, energy storage DC nano-grid (ESNG) concept is proposed [3]. ESNG has an internal common bus as the back-bone to integrate any desired number of energy storage devices (EnSD). The internal common bus is selected to be DC. The reasons to select DC rather than AC are:

a. Most of energy storage technologies are DC-output, e.g. standard batteries, flow batteries and ultra-capacitor. For flywheel, DC output is also preferred with use of variable frequency DC/AC inverter.

b. Use of common DC bus helps avoid AC synchronizing problem and improve the system robustness. The common DC bus should have sufficiently high voltage, for example, 800 VDC or higher, to avoid low efficiency. For same power rating, use of higher voltage rating results in lower current rating (IDC), and thus, lower power loss over resistance (R) of bus bars, power cables and connectors as:

$$P_{Loss} = I_{DC}^2 \times R \qquad (i)$$

Lower current rating is also preferred by DC circuit breaker when voltage rating increases, on resistance (Ron) of power electronic devices increases exponentially [6]. Because there are usually more than two power switches conducting at the same time in power converter, conduction loss then increases as:

$$P_{cond} \geq I_{DC}^2 \times 2R \qquad (ii)$$

Inside ESNG, all EnSDs are connected to DC bus via power electronic interfaces, i.e. bidirectional DC-DC converters (batteries, ultra-capacitor), bidirectional DC-AC converters (flywheel), or power conditioning units (SMES etc.). Fig.5 illustrates general structure of the proposed ESNG including BESS1, BESS2, ultra-capacitor and flywheel.

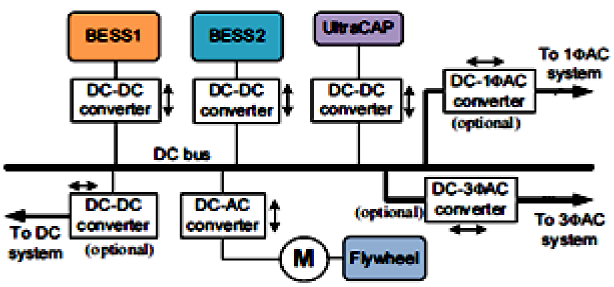


Figure 5: Energy Storage DC Nano-grid [5]

Main advantages of ESNG are:

a. ESNG offers a wide range of power, especially high power level for applications of micro-grid and renewable energy plant by actively integrating different energy storage technologies, from standard battery and ultra-capacitor up to flywheel and flow battery, and higher.

b. ESNG incorporates BESS, which passively integrates basic cells of single type, and HESS, which actively integrates 2 types of energy storage. Inside ESNG, energy storage packs and modules constructed from basic cells are used as passive integration. In addition, the energy storage packs and modules are actively integrated via power electronic interfaces. More than two types of energy storage can be used in ESNG. Depending on design objectives.

c. ESNG can have high energy density, high power density and battery lifetime extension at a minimal cost.

d. ESNG provides ease of system expansion and component replacement. As a nano-grid, ESNG has an open physical architecture to easily add or remove components inside. With active power electronic interfaces, power flow is flexible amongst EnSD. Therefore, online replacing a component without affecting other components is easy to obtain.

e. ESNG has high inter-connectivity interfacing other systems, such as DC system, single-phase AC system and 3-phase AC system. ESNG can be used as power buffer and energy link amongst these systems, for example, between AC micro-grid and DC micro-grid or used to support merely [4].

Therefore, energy distribution in ESNG has to be managed such that longevity of battery-based EnSDs is extended. In practice, electrical energy storage system such as battery storage system is often equipped with Battery Management System (BMS). The BMS provides the following functions to the BESS:

- Monitoring voltage, temperature, SOC, SOH, current.
- Protection for over-current, over/under-voltage, over/under-temperature, overpressure
- Balancing SOC of cells.

VI. INTEGRATION AND CONTROL IN NANOGRID

To obtain the reliability of power transmission system we need to interconnect the distributed system of generation resources to the same transmission grid as central stations. For the integration of these resources many technical and economic issues arises in the grid. Power control system addresses the following issues: protection, power quality, harmonics, stability, reliability and losses in power system. [7].

Performance of all equipments used in grid must be evaluated before installing in the grid. Combinations of the all devices for distributed and central station generation must be checked [6]. Frequency and voltage must be control for large scale installation of distributed system of generation which may affect functions of grid and allocation of reserves. One way to avoid these variations we can use storage system in grid. So in virtual power plants and grid energy storage system must be added to the grid.

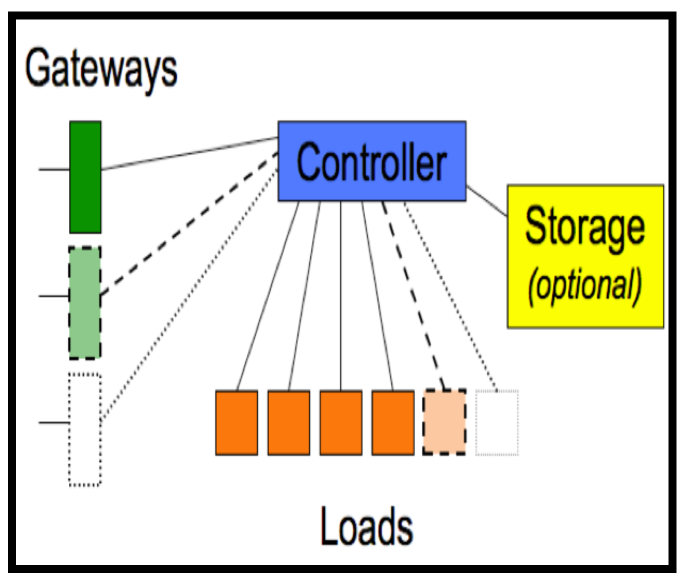


Figure 6: Nanogrid Control Systems [5]

VII. GRID CONNECTED PV SYSTEM DESIGN FOR DOMESTIC LOAD

The PV Solar system can be divided into two categories Grid Connected system and standalone system. The Grid Connected System: this can be divided into two categories.

- Small power applications such as house electric items for large power applications such as solar plants
- Stand-alone System: This may be house battery and interaction with grid.

VIII. INTEGRATION OF ELECTRICITY NETWORKS

Energy storage can be integrated at different levels of the electricity system:

- Generation level: Arbitrage, balancing and reserve power, etc.
- Transmission level: frequency control, investment deferral
- Distribution level: voltage control, capacity support, etc.
- Customer level: peak shaving, time of use cost management, etc.

Table 3: Specifications of Components in Residential Micro Grid

Device	Capacity
PV Source Wind Energy Diesel generator	90 KW 100 KW 100KW
Residential load	1200 KW
ESNG	1950 kWh
Battery Pack 1 (lead acid) Battery Pack 2 (li-ion) Ultra-capacitor	1200 KWh 600 KWh 80 KWh

XI. MATHEMATICAL MODELING

The following equation used for calculation of active reactive power and harmonics. The following model shown in figure 7 is used in this paper. The PV array connected to nanogrid via inverter and PV meter.

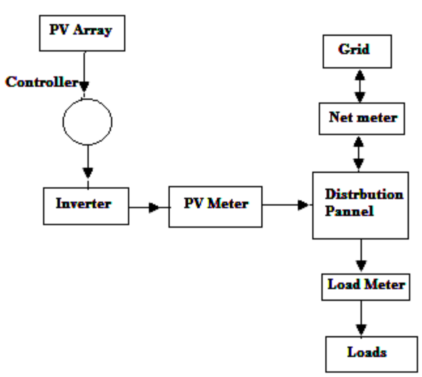


Figure 7: PV solar cell with Grid Connection

Power in the grid

YE = I, P+JQ =EI (i)

The magnitudes of voltage and active and reactive power generated by Photovoltaic and Slack bus, can only operate for certain values lie in a range.

$E_K \in \{E_{k,1}, \ldots\ldots, E_{k,m}\}, |I_k| \leq I^{max}$ (ii)

For k ϵ Step-down

$E_i^{min} \leq |E_i| \geq E_i^{max}, |I_{i,k}| \geq I_i^{max}$ (iii)

$P_i^{min} \leq P_i(V; \pi_i) \leq P_i^{max}$ (iv)

$Q_i^{min} \leq Q_i \leq (E; \mu_i) \leq Q_i^{max}$ (v)

For the selected area value of ΔU selected as

$\Delta E \geq 4\%$
$\Delta E \geq 3\%$
$\Delta E \geq 2\%$
$\Delta E < 2\%$

Where

E = Voltage, ΔE = Change in voltage and I= current

Monthly energy production = PV Plant capacity x Average Sunshine hours x no of days in month …… (vi)

Total losses = Temperature losses+ Module soiling losses+ Modules mismatch+ DC Cable losses+ Solar radiation losses (vii)

Energy generated after consider module level losses = ideal energy generated without losses x (1 – PV module level losses)

Energy generated after consider module level losses = 15345 kWh x (0.798) = 1224.5310 kWh.

X. SIMULINK MODEL FOR NANOGRID

The following Simulink modes are used in this research work. In Microgrids all, renewable energies are integrated in DC system and other is for integration of energy from grid for DC bus Bar shown in figure 10.

Load Profile Simulation

For the load profile new elements like PV, E-car, batteries, fuel cells, wind, etc can be used. For simulation methods Load profile simulation used for domestic load. Unbalanced dynamics protection/restoration strategies used for in proposed model. The load of 50 houses selected for simulation as shown in figure 8.

Load Flow

The active power supply remains constant, independent of the voltage. If this is above or below predefined voltage limits, the DC-Infeeder is removed from the network. The reactive power demand for the inverter is simulated by a factor for the required reactive power. Photovoltaic in feeders behave the same way in any procedure based on load flow.

Short Circuit: Maximum: The current supply is constant and calculated from the installed peak power.

Short Circuit: Minimum: This method ignores DC-In feeders.

Short Circuit – Standard: The current supply is constant and calculated from the installed peak power and the current factor for active power. In all the procedures based on short circuit (multiple fault, protection, etc.), photovoltaic supply behaves in the same way.

Figure 8: Selected 50 Houses load for Smart Grid

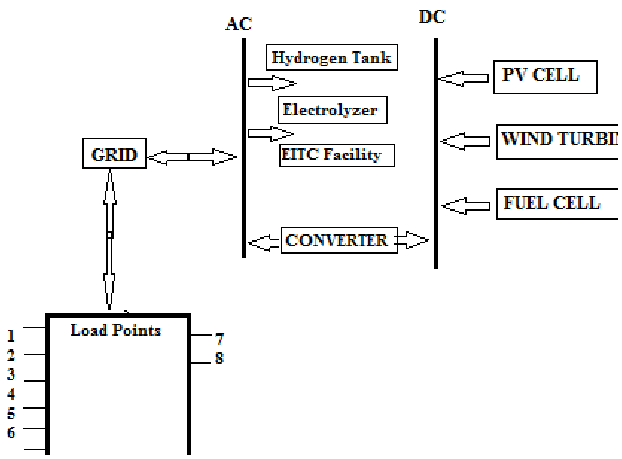


Figure 9: Simulink Model

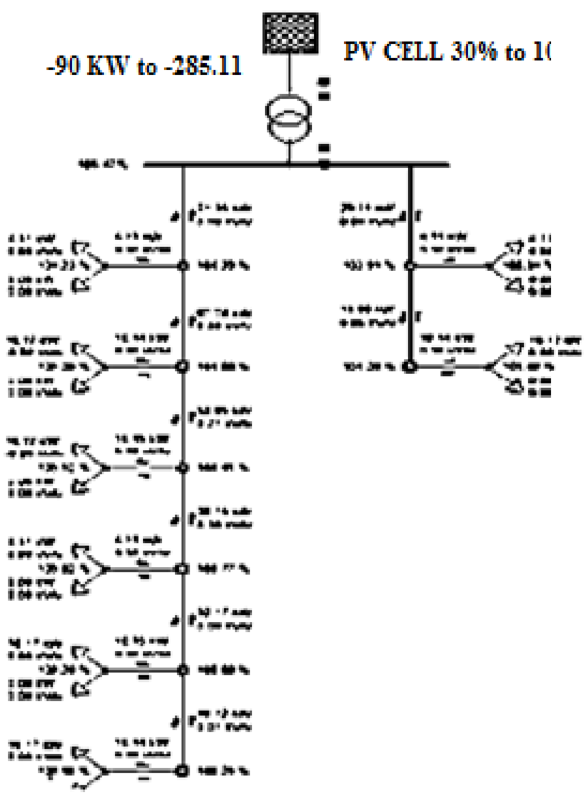


Figure 10: Load Distribution Diagram

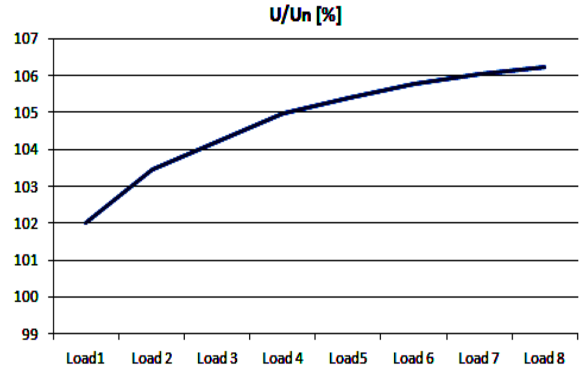


Figure 11: Loads Efficiency with 30% PV Efficiency

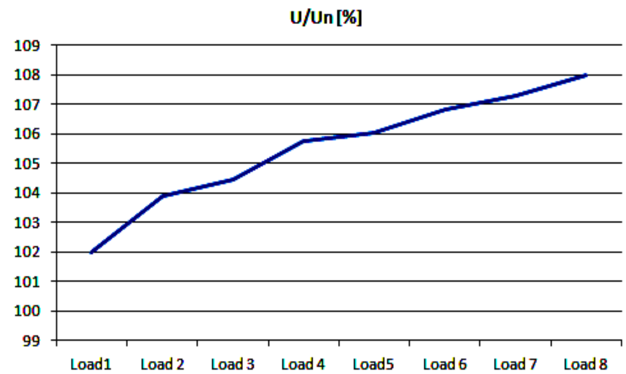


Fig.12 Loads Efficiency with 40% PV efficacy

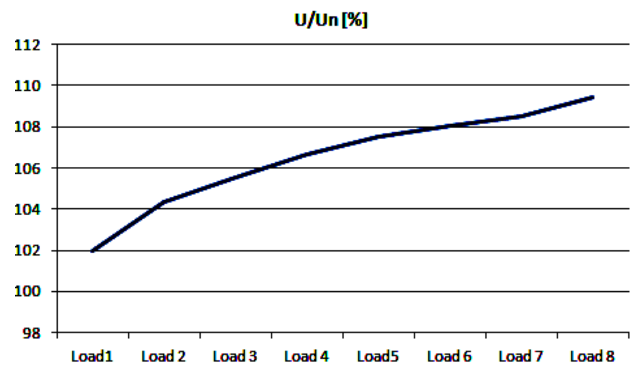


Figure 13: Loads Efficiency with 50% PV Efficiency

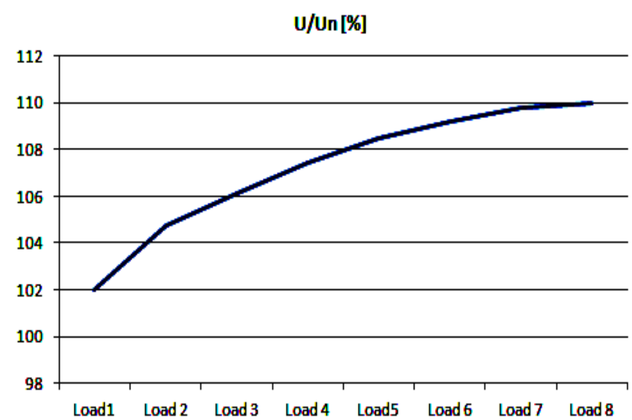


Figure 14: Loads Efficiency with 60% PV Efficiency

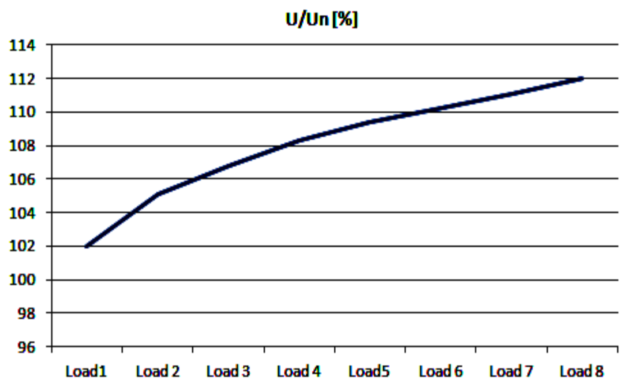


Figure 15: Loads Efficiency with 70% PV Efficiency

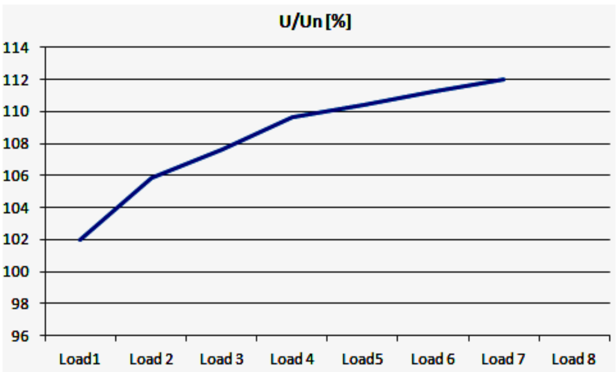


Figure 16: Loads Efficiency with 80% PV Efficiency

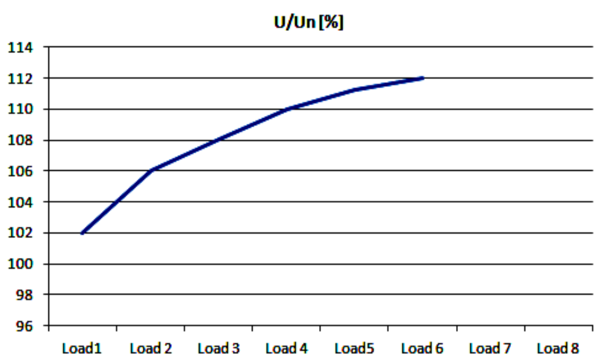


Figure 17: Loads Efficiency with 90% PV Efficiency

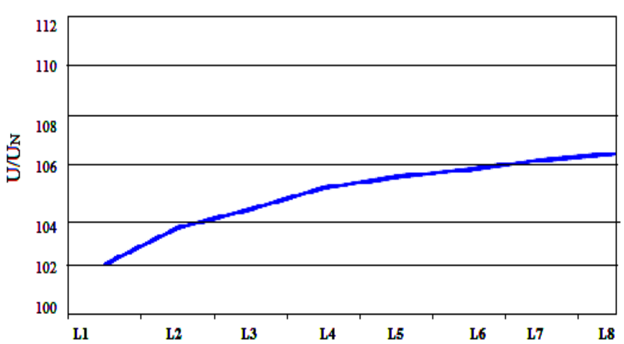


Figure 18: Load and Efficiency Curve for 100% PV

From the above figures 11 to fig 18, it can be concluded that as the Load efficiency of the PV cells increase the distribution curve limited to support loads. It can be seen at 30% load efficiency it covered maximum area as the efficiency increased to 112% in microgrid the curve limited to wide area. Eight points of loads were selected. In future all alternative energy resources can be applied in microgrid using same method.

XI. CONCLUSIONS

In this paper we proposed the concept of energy storage DC nano-grid which is an integration platform for various energy storage technologies to achieve a system with high performance, high flexibility and minimized cost. Energy management, power management and dynamic control of energy storage DC nano-grid are presented. This paper has also proposed solution to three main issues related to applications of energy storage DC nano-grid in modern power system, which are intermittency of renewable energy sources, instability caused by constant power load and constraints of energy storage devices.

The analysis, proposed solutions and verification have been performed for applications of energy storage DC nano-grid in a micro-grid and in a wind power plant. A control strategy with dynamic behavior of energy storage, DC nano-grid having wind power plant for stable operation of small-signal and large-signal is presented. Design approach to control energy storage devices in energy storage DC nano-grid to operate in a stable way under constant load condition. The approach is to individually design the energy storage devices that remain stable when constant load is used, and use of dynamic-blocking diodes to cancel dynamic interactions amongst converters. A bounded-input bounded-output stability criterion for multi-source multi-load DC system is also provided.

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