National Technical University of Athens

SMART RUE smartgrids Research Unit ECE NTUA

Best Practices of Rural Electrification in Developing Countries

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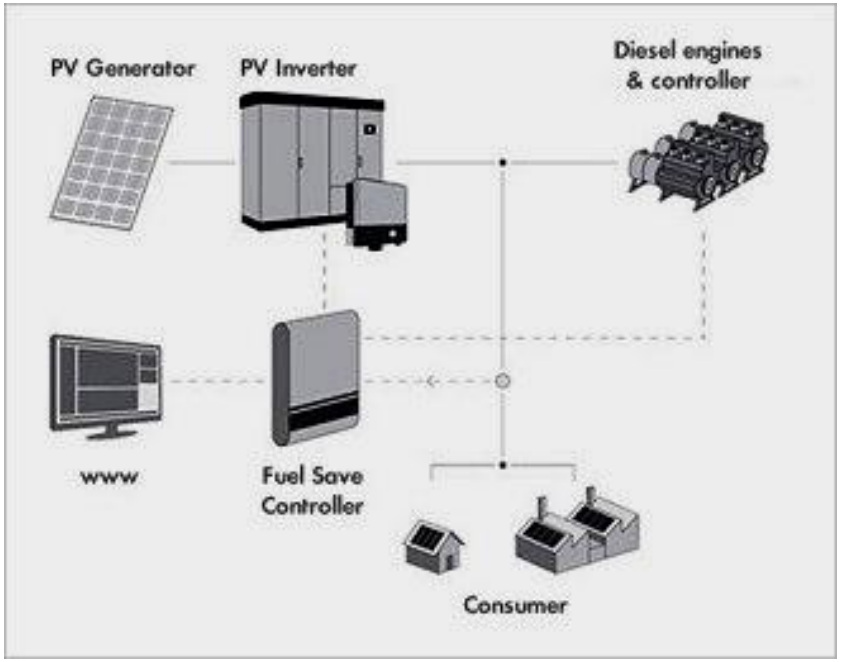
Overview

- Technologies and case studies
  - Diesel Based PV/Wind Hybrid
  - PV/Wind with Battery Storage
  - Solar Lanterns and Irrigation System
  - Micro-hydro
  - Biomass
- Case Study of Hybrid System in rural Ethiopia

Technologies and Case Studies

Diesel Based PV/Wind Hybrid

- Diesel Generators: Most common
  - High operation costs: fuel, transportation, maintenance
- Hybrid: reduction in fuel cost and generator use.

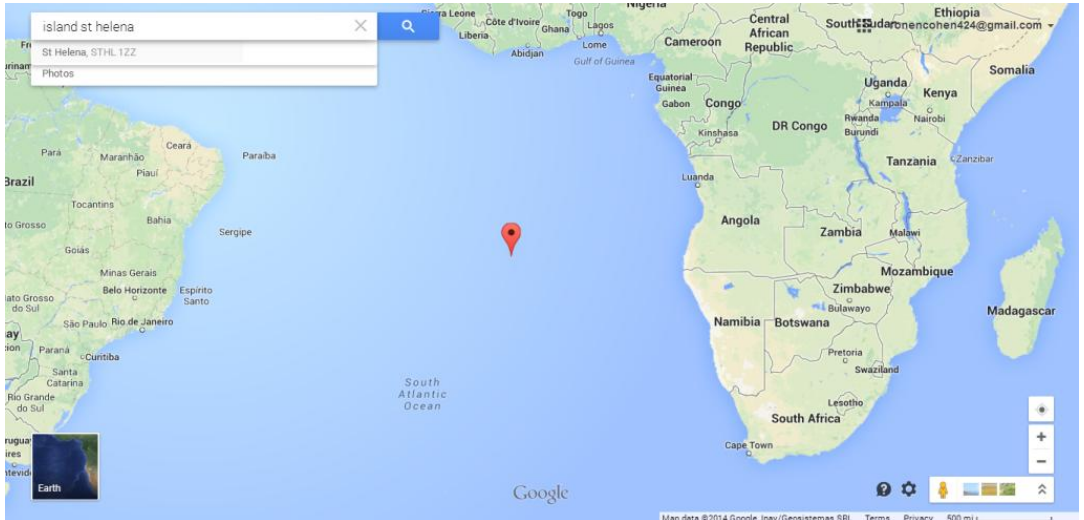


Technologies and Case Studies

- Diesel Based PV Hybrid
  - Applied to existing diesel systems and also to new-built systems
  - PVs cover the morning to mid-day load, whereas the diesel genset can meet the load demand for many hours overnight.
  - Avoiding a low load factor, reverse power flows and insufficient spinning reserve due to the intermittent renewable source is considered into the design and operation of the system.
  - 100 Pilot Projects: Kenya, Rwanda, Mali, Senegal, Tanzania. PV capacity from 5 to 30kWp

Technologies and Case Studies

- Diesel Based Wind Hybrid
  - Feasible solution in areas with a good wind resource.
  - Saint Helena Island, in South Atlantic Ocean (4,200 population)
  - Wind turbines from 50kW to 300kW provide 20% of the islands energy needs thus saving the equivalent energy cost in diesel fuel and transportation costs.



Technologies and Case Studies

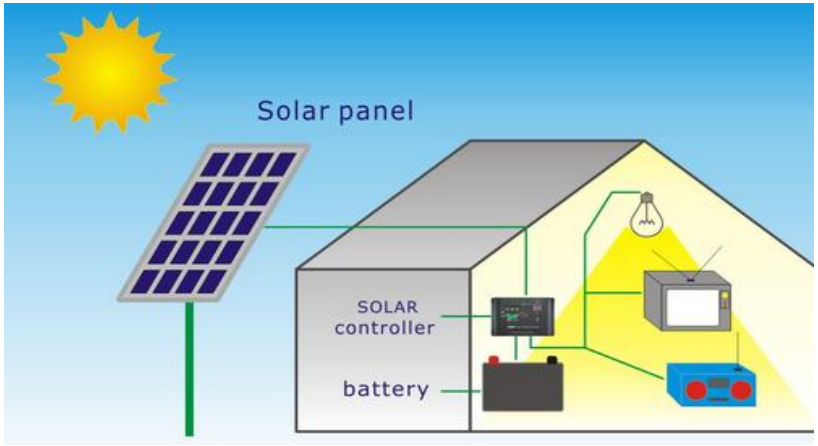
- PV/Wind with Battery Storage

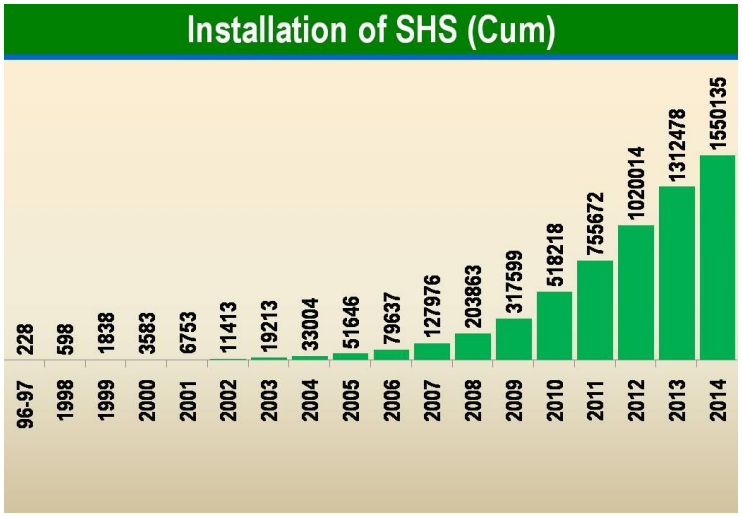
  - Main energy provider is the renewable resource.
  - Diesel generator has a back-up role or is not present.
  - A Wind Turbine can be combined with PVs due to their complementarity
  - The Wind Turbines can be manufactured in a community level using local materials and approaches.

Technologies and Case Studies

Individual home system and community systems

- Story of Bangladesh





- *Solar Home Systems (SHS)*
- 1.6 million *SHS* of 50Wp that supply DC loads have already been installed.
- Target of 4 million by 2015.
- Different paying methods:
  - full amount in small parts becoming the owner of the system at the end of the payment.
  - Smaller amount for a longer period and rent the equipment from the seller.

Technologies and Case Studies

- Lao PDR
  - Over 9000 SHS and community centers
  - Target of 90% electricity coverage by 2020.
- Peru
  - 3000 SHS since 2012
  - The government funds 80% of the total cost of the system, leaving the rest 20% to be covered by the users.
  - Educating and training people to the daily operation of SHS.
- India: 670,000 SHS
- Indonesia 200,000 SHS
- Kenya, Ghana and Ethiopia are making efforts

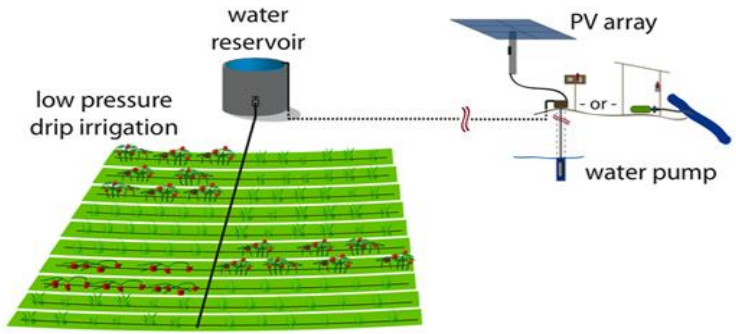
Technologies and Case Studies

- Solar Lantern
  - PV, battery and LED lamp
  - Aiming to replace the use of Kerosene Lamp.
  - According to World Health Organization nearly 1.2 million people die from indoor air pollution every year, a large proportion of which is due to the use of Kerosene lamps.
  - 800,000 in use in India, 200,000 in Bangladesh, and many in other countries in sub-Saharan Africa and Asia.

Technologies and Case Studies

Solar Photovoltaic Irrigation System

- Stand-alone, often battery-less solar photovoltaic system that can pump water.
- Minimum maintenance.
- Ideal for remote locations.



- Benin
  - 60% of households lack food-security in rural areas
  - Solar-powered irrigation systems are used to irrigate fields for consumption and sale during the dry season.
  - Over 48,000 people are already benefiting from these systems.
  - Electrification of households and community centers is the next step

Technologies and Case Studies

- Micro-Hydro

  - Adaptable to local conditions.
  - Energy production 24 hours/day at full capacity.
  - Can promote local technology and skills, with the transfer of necessary knowledge and the manufacture of several components locally.
  - Cost effective

Technologies and Case Studies

- Nepal
  - Successful cooperation of NGO with government promoted local manufacturing
  - Run-of-the-river plants, that use the natural flow of the river to generate power.
  - 2,500 micro-hydro plants have already been installed with a total capacity of 20 MW.

Technologies and Case Studies

- Nepal

- A hybrid system of a micro-hydro plant of 20kW, a 3kW wind turbine and a 5kW PV system exists in villages of Thingan and Kolkhop.

Technologies and Case Studies

- Biomass
  - Already used for cooking and heating
  - Rice, cashew nuts, coconut shells or other woody biomass can be used for the production of electricity.
  - From a few kWs to several MWs
  - Possibly lower cost than diesel generation

Technologies and Case Studies

- India
  - A system of 5 gasifiers, of 100 MW each, provides electricity to the isolated island of Gosaba and its 1150 families
  - Microgrids in electrified areas in cases of unstable grid (e.g. for the electrification of public spaces or water pumps)
- Cambodia
  - Over 100 biomass gasification plants with average capacity of 200kW.
  - The rice husk production could be enough to completely cover the electricity demand.
- Thailand
  - 20 plants from 10kW up to 400kW.

Benefits from Rural Electrification

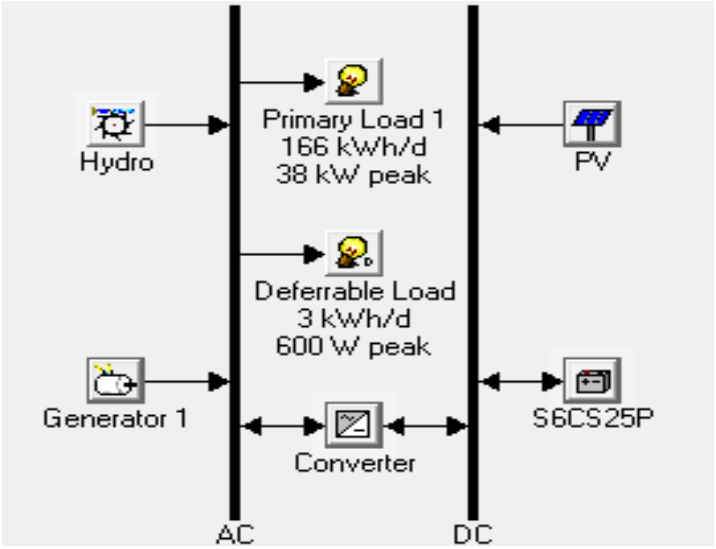
- Access to reliable electricity brought significant changes in both social and economic aspects of everyday life.
- Social Impact
  - Higher quality of light
  - Free from inhalation of toxic kerosene smoke.
  - Improved access to information, through mobile, television and radios.
  - Children can study longer and more effectively.

Benefits from Rural Electrification

- Economic Impact
  - The monthly cost of kerosene and diesel has been replaced by the payments for the micro-grid
  - New income earning activities are created, such as mobile phones and battery charging.
  - New job opportunities and new workshops are easier to create and operate with the presence of electricity, which strengthens the local economy.
  - Enterprises are able to remain open after dark

Case Study of Hybrid System in rural Ethiopia

- Ethiopia has one of the lowest rates of electricity coverage, which is about 16%.
- Hybrid system that consists of a small hydropower plant, a diesel generator and solar panels along with batteries
- HOMER software was used
- 105 families, school, health center, flour mill
- Deferrable load: water pumps
- 166 kWh/day



Case Study of Hybrid System

- Optimization results

	PV (kW)	Hydro (kW)	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen (hrs)
	7.4	20.7	7.13		9.0	LF	$ 71,923	884	$ 82,513	0.112	0.98	0.01	679	839
		20.7	7.13	8	9.0	LF	$ 73,610	846	$ 83,746	0.113	1.00	0.00	145	179
		20.7	14....			LF	$ 59,872	2,027	$ 84,141	0.114	0.96	0.00	1,762	1,204
	7.4	20.7		8	9.0	CC	$ 77,682	824	$ 87,552	0.119	1.00	0.01		
	7.4	20.7	7.13	8	9.0	LF	$ 81,620	882	$ 92,177	0.125	1.00	0.00	130	157
	22.2		14....	8	13.5	CC	$ 63,561	10,314	$ 187,071	0.254	0.53	0.01	9,365	3,918
			14....	16	13.5	CC	$ 49,228	17,133	$ 254,404	0.346	0.00	0.01	16,504	5,379
	22.2		21....		13.5	LF	$ 57,802	18,926	$ 284,453	0.385	0.41	0.00	16,497	7,220

- Micro-hydro is not enough to solely support the load
- Most economic option: combination of micro-hydro plant (20.7 kW), diesel generator (7.13 kW) and PV panels (7.4 kWp).
- 98% renewable penetration
- The national energy tariff of energy in Ethiopia is around 0.04 $/kWh which is considerably lower than that of the proposed system 0.112 $/kWh.

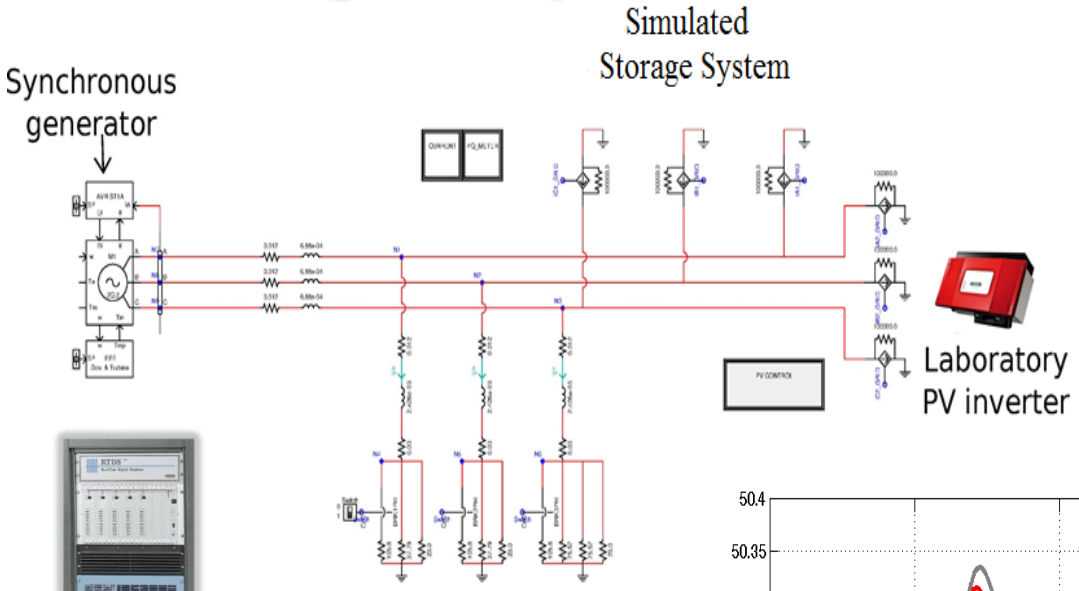
Case Study of Hybrid System

- Comparison between Diesel-only, and Diesel-PV hybrid system.

PV (kW)	Gen (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen (hrs)
11.1	21.38	LF	$ 37,573	23,230	$ 315,761	0.428	0.22	0.01	20,192	8,760
	28.52	LF	$ 25,755	30,326	$ 388,928	0.527	0.00	0.00	26,327	8,760

- Introducing PV generation to a diesel based system, reduces the cost of energy and the fuel consumption

HIL simulation for dynamic studies of off-grid systems



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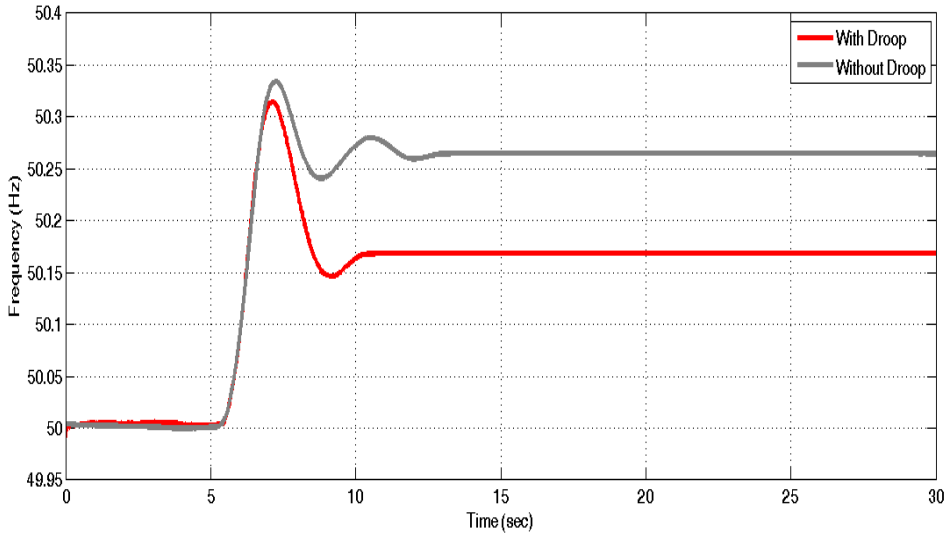

Conclusions

- United Nations has set 2030 as a target date for universal access to modern energy services.
- Micro-grids can provide cost-effective and reliable energy in remote areas in diverse ways

- Case study:
- Micro-hydro was the cheapest solution
- The cost was higher than the utility grid
- Introducing PV generation to a diesel based system reduces the cost of energy

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Thank you for your attention

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