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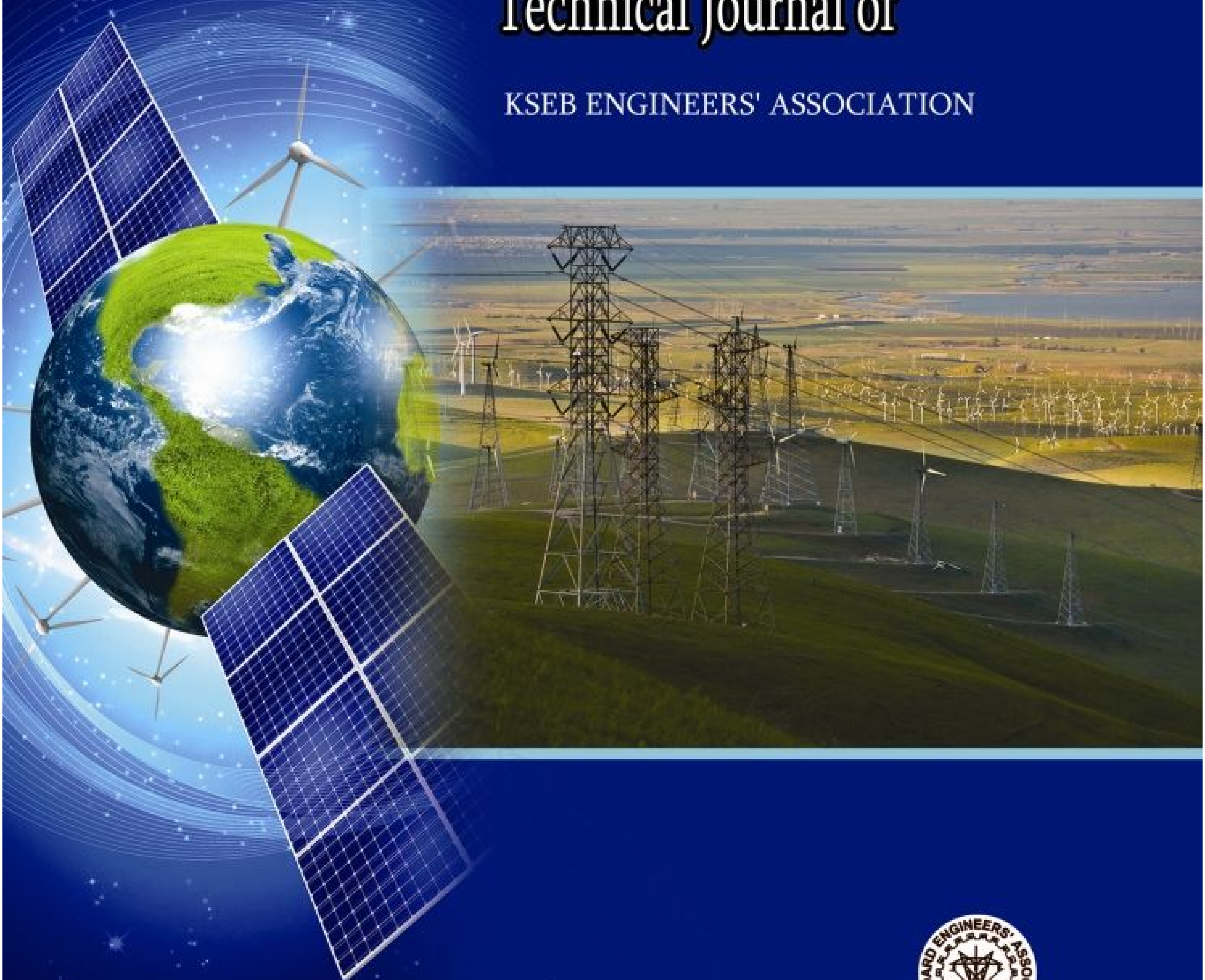

Theme: Energy Planning for the Sustainable Development of Kerala

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Editorial

The energy crisis and the threats of climate change coerce us to make the first move for a energy planning for the sustainable development of our state. Energy planning is the process of developing long-range policies to guide the future of energy systems ranging from local to global. Energy planning is often conducted within Governmental organizations or power utilities or producers. Energy planning may be carried out with input from different stakeholders including government agencies, local utilities, and academia. Energy planning is often conducted using integrated approaches that consider both the provision of energy supplies and the role of energy efficiency in reducing demands.

A new trend in energy planning known as Sustainable Energy Planning takes a more holistic approach to the problem of planning for future energy needs. Sustainable energy planning become a key factor in the sustainable development of the state.We want to develop self sufficiency and security in our energy sector while employing best available practice in the planning processes. The process incorporate all core area of Engineering that ensures efficient utilisation of production of energy.

Sustainable energy planing is based on a structured decision making process with the following steps; examination and formulation of problems and opportunities, modeling, presentation of the result of model analysis in structured manner, interpretation of the results, quality assurance, publication and implementation of a range of policies, regulations, procedures or tasks which together will help to achieve the goals of the sustainable energy plan.

The article included in this edition are drawn from academia as well as from industrial experts and arranged in logical manner to ignite the discussions on energy plan for the future of our Kerala.

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Electrical Energy and Sustainable Development: A Kerala Perspective

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INTRODUCTION

The economic, social and cultural development of human society is highly dependent upon a consistent supply of energy. Sustainable development is therefore only possible, if our society attempts to find and implement environmentally compatible, socially acceptable and economically viable means to acquire its energy services. Sustainability, a crucial factor in future energy planning, needs contributions from energy experts, scientists, energy companies, environmental organizations and government policy makers. Building blocks of sustainable electrical energy planning include energy conservation, renewable energy sources, demand management options and efficient transmission systems [1].

Interrelated factors like economic conditions, fuel availability, technology developments, policy reforms and environmental concerns control the complex functions involved in electricity generation, transmission and distribution. Incorporation of sustainability aspects in future electricity reforms and energy policy is indispensable to reduce the environmental impacts of power generation. Energy security and access to energy for the poor should become among the objectives of the electricity sector market reforms. Formulation of strategies which balances economic development against environmental protection and energy security under the principles of energy conservation is vital for sustainable development. As electrical energy consumption is significantly correlated with social, economic and environmental development, electricity sector performance indicators can be used to assess the regional level sustainable progress.

The main objective of this paper is to analyze the technical performance of Kerala power system in last two decades (1990-2010) from a sustainability point of view. The paper identifies some power system based key indicators and evaluates their contribution to sustainable development.

TECHNICAL PERFORMANCE OF KERALA POWER SECTOR

There is no unique set of sustainability indicators; instead specific indicators need to be identified according to the context and application. The true indicator of sustainable development is the level of energy services enjoyed by the population, particularly by its poorest sections, rather than the magnitude of per capita energy consumption [2]. However, a few popular key technical indicators are normally selected to provide a gross idea on how the system is performing in providing the basic intended energy services [3]. Table 1 provides a brief profile on the growth of Kerala power system in the last two decades (1990-2010).

Table 1. Growth profile of Kerala power system 1990-2010

Indicator	1990-91	2000-01	2009-10
Connected load (MW)	4643.00	8551.00	15866.55
Number of consumers (Lakh)	34.5	64.46	97.43
Installed capacity (MW)	1477	2420.68	2746.00
Gross annual generation (M U)	5491.00	6967.00	7240.38
Per capita consumption (kWh)	185	311.67	474
Energy export (MU)	4.73	-	53.9
Energy import (MU)	1303.83	5543.00	10199.96
Total energy sales per annum including export (MU)	5332.00	10319.00	14024.99
Domestic sector electricity sales (MU)	1841	4688	6559
Commercial sector electricity sales (MU)	706	828	1793
Industrial sector electricity sales (MU)	2617	3784	4481.09
Agriculture sector electricity sales (MU)	235	350	257
T & D losses (%)	21.57	17.21	19.41
Number of street lights	521297	763912	1148220
Number of electrified villages	1364	1364	1364
Percentage of households with electricity (%)	48.4	70.24	84
Average production cost of electricity(Ps./Kwh)	70.34	286.17	457
Average tariff (Ps./kWh)	60	169.14	338

Source: Power System Statistics, KSEB, 2010

In the decade 1990-2000, percentage increase in the installed capacity was 63.9% corresponding to an increase of 84.16 % in connected load. But the percentage increase in the installed capacity was only 13.4% for a connected load increase of 85% during 2001-2010. This inadequate capacity building is certainly a major challenge to the sustainable development of Kerala state.

Table 2. State wise capacity addition during 11th plan (1997-2012)

State	Capacity addition (MW)	Ranking
AndhraPradesh	4579	5
Assam	37.2	23
Bihar	1000	14
Chattisgarh	5403	4
Delhi	858	15
Gujarat	8257.5	1
Hariyasna	3460	8
Himachal Pradesh	1292	12
Jammu& Kashmir	570	18
Jharkhand	2050	10
Karnataka	3720	7
Kerala	100	21
MadhyaPradesh	1230	13
Maharashtra	5476	3
Meghalaya	84	22
Orissa	1950	11
Punjab	500	20
Rajasthan	2520	9
Sikkim	510	19
Tamilnadu	842.2	16

Tripura	21	24
Uttarkhand	704	17
UttarPradesh	4080	6
WestBengal	5720	2

Source: Power scenario at a glance, Central Electricity Authority, November 2012

As shown in Table 2, rank of Kerala based on capacity addition made by the state during 11th plan is 21 and is an indication of distressing condition of Kerala power sector. Suitable policy back up and regulations from the government is inevitable for the installation of conventional and non conventional power plants. Further delay in actions will lead Kerala to energy poverty and make it a state not suitable for sustainable living.

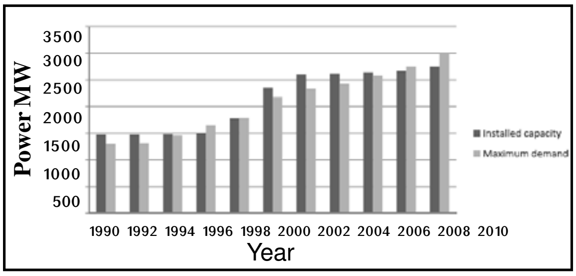


Fig. 1 Installed capacity and maximum demand of electricity in Kerala 1990-2010

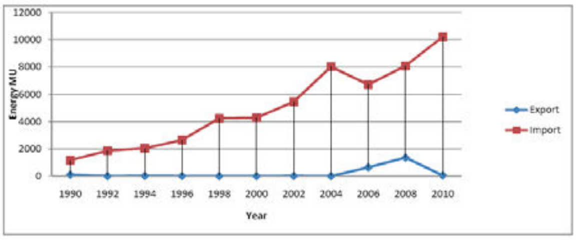


Fig. 2 Export and import of electrical energy in Kerala 1990-2010

Fig.1 represents the installed capacity and maximum demand on Kerala power system from 1990 to 2010. Installed capacity exceeded maximum demand till 2006. But 2007 onwards the situation changed and deficiency gap is increasing year by year.

Referring to Table 1, energy import in the period 1990-2010 is increased by eight times. From Fig.2 it is intelligible that the import is shooting up and export is trivial. This is a clear indicator of increasing uncertainty in availability of electrical energy. This may adversely affect the state's capacity to provide modern energy services at socially affordable prices in a sustainable manner for all.

Table 3. Growth in electricity per capita consumption of south Indian states

State	Percapita (kWh)	consumption
	2000-01	2009-10
AndhraPradesh	391	1013.7
Karnataka	380.1	873.05
Kerala	311.67	536.78
Tamilnadu	484.4	1210.8
All India	355	739.44

Per capita electrical energy consumption is one of the indicators of economic conditions and is an important criterion for rating the standard of living in the state. As shown in Table 3, per capita electricity consumption of Kerala is far below compared to other south Indian states and all India average. This indicates the less economic activities in the state and shows the poor progress in the economic domain of sustainability.

Transmission and Distribution (T&D) losses, which was 21.57% in 1991 decreased to 17.21% in the 2001. Due to the inclusion of losses in interstate transmission lines, T &D losses increased to 30.76% in the year 2002. From the Table 1, it can be seen that by 2010, the value reduced to 19.41%. This is achieved by the earnest efforts of Kerala State Electricity Board (KSEB) for proper energy accounting, maintenance and provision of more distribution transformers and feeders. Most of the developed countries have T & D losses less than 10%. So the sustainable development prospects emphasize the need for more efficient technical performance options in T&D sector. Energy efficiency improvement at utility level can be achieved by total accounting of T&D losses at feeders and distribution transformers, energy received in each substation, 11kV out-going feeders and the energy billed. Creation of consumer data base and consumer indexing can help to a great extent in this regard. Consumer indexing is the indexing of all consumers in all categories so that the consumers can be segregated feeder-wise and distribution transformer-wise.

Even though all the villages in Kerala are electrified, grid electricity has not reached to whole population and modern energy services are not available to 6 %

households in the state [5]. As social sustainability is about the equity based on a fair distribution of resources, high electrification rate can be considered as an indicator of social sustainability progress of the state.

Referring to Table 1, the unit cost of production of electricity, which was 70.34 paise in 1990-91, indicated average annual increase of 15% and increased to 286.17 paise and 457 paise in 2000-01 and 2009-10 respectively. But the average revenue realised through electricity tariff which was 60 paise in 1990-91 increased to only 338 in 2009-10. The average tariff throughout the last two decades was totally inadequate to cover even the production cost of energy and this has affected the financial performance of KSEB.

Table 4 provides an illustration on the aggregate operational performance of generating stations in the state.

Table 4. Operational performance of Generating stations

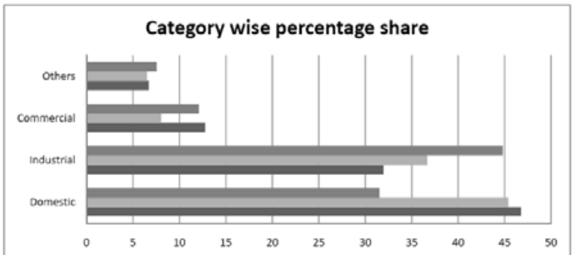
Year	Utilisation (kWh/kW)	Utilisation factor (%)	Load factor (%)
2000-01	2878.11	32.85	61.66
2004-05	2436.57	27.81	59.29
2008-09	2371.12	27.06	64.66
2009-10	2636.70	30.09	66.2

Evaluation of utilisation is based on the electrical energy generated per annum (kWh) per kW of installed capacity. Utilisation factor (the ratio of kWh generated to the maximum possible generation in a year) and load factor (the ratio of average load to maximum demand) of generating stations play key roles in determining the overall cost per unit generated. Higher these factors, lesser will be the cost per unit generated. But throughout the last decade, the utilisation factor was in the range of about 30% and load factor around 60%, which are rated as 'poor', depicting the sub-optimal performance of the generating stations. In the context of inadequate capacity additions and increasing demand, improved performance of generating stations and better utilisation of available capacity are highly imperative.

Fig 3, shows the percentage share of different consumer sectors to the total electricity sales in 1992-93, 2000-01 and 2009-10. The agricultural sector has minimal electricity consumption compared to residential, commercial, and industrial sectors. Its share has decreased from 3.4% in 2000-01 to 1.8% in 2009-10. This indicates the state's inability to achieve food security.

As shown in Fig.3, domestic sector share has an increasing trend and accounted for 46.76% of total electricity sale in 2009-10. So, residential sector consumers must be identified as a major target group for energy conservation and management activities in the state. A comprehensive understanding of economic, environmental and consuming behaviour factors which significantly influence the residential sector energy consumption is imperative to design effective local energy policies.

The share of commercial sector's electricity consumption to the total share has grown from 2000 to 2010 while percentage share of industrial sector has dipped, reflecting the changing structure of Kerala's economic activities from manufacturing to services.



	Domestic	Industrial	Commercial	Others
1992-93	31.52	44.81	12.09	7.56
2000-01	45.4	36.67	8.02	6.51
2009-10	46.76	31.95	12.78	6.71

Fig. 3. Percentage share of different consumer sectors

Table 5 gives the percentage change in the electricity consumption of different consumer sectors from 2000-01 to 2009-10. Consumption in commercial sector has increased in the last decade at a much faster pace compared to other sectors. This indicates the necessity of planning and implementing effective energy management measures in the commercial sector.

Table 5. Percentage change of electricity consumption of different consumer sectors (2000-2010)

Consumer sector	Energy consumption(MU)		Percentage change
	2000-01	2009-10	
Domestic	4688	6559	(+) 39.9
Industrial	3784	4481.09	(+) 18.4
Commercial	828	1793	(+) 116.4
Agriculture	350	257	(-) 26.57

GENERAL EVALUATION

Rapid urbanization and population density are the two key characteristics of the state. As per census 2011, urban population is 47.72% and population density is 859 persons/ sq.km corresponding to the national averages of 31.16% and 364 persons/ sq.km [5]. The additional precautions to be undertaken and negative effect on bio-diversity have limited the scope of new large hydro electricity plants. But Kerala is blessed with large amount of renewable natural sources like solar radiations, small hydro power, wind and biomass. Sustainable development includes the development in social, economic, environmental dimensions. Pollution free renewable sources generally cause less environmental impact. Also as they favour decentralized power systems, they can contribute to the social and economic development of rural population. So through the effective utilization of renewable resources, Kerala has the potential to be in the path of sustainable development.

Also energy efficiency can be thought of as a supply of resource - often considered an important, cost-effective supply option. Investment into energy efficiency can provide additional economic value by preserving the resource base and mitigating environmental problems. Implementation of energy efficiency measures at supply side and end use level would help the state electricity board to improve its financial performance without considerable hike in tariff.

CONCLUSION

This study reviewed the performance of Kerala power sector in the past decade with the help of a few technical indicators, focussing the sustainable progress of the state. Findings indicate that the power sector could not contribute effectively in this regard. Inadequate capacity addition, poor utilisation rate of generating stations and increasing share of import are constraints to the sustainable development. The power crisis in the state will be worsened unless the government makes mandatory plans to diversify the energy sources in domestic, commercial, and industrial sectors and adopt new available technologies to reduce energy wastages and to save cost. Improved performance strategies with clear futuristic planning in the power sector are unavoidable for the sustainable development of the state. This study is also useful to understand the implications and impact of electricity sector in the sustainable growth of the state. Moreover appropriate state-specific energy policies and strategies need to be developed to encourage energy efficiency, promote the utilization of renewable energy sources and minimize environmental impacts.

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Grid-interactive SPV Rooftop plants:

- A Solution for Energy Crisis

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1. Introduction

Kerala has been largely depending on hydro electric power plants for electricity power generation. Due to climatic changes and lack of rainfall the generation from hydroelectric power plants is greatly affected and this is affecting the management of electric grid in Kerala. Kerala now realized the need for alternate source of electricity. It is during 2012 that the Planning Board of the State has decided to give more thrust to Renewable Power Generation. The Board decided to promote new technologies to generate electricity. The prestigious 10,000 Solar Roof-top programme was launched to generate more power from solar energy and to offset the peak load demand of electricity. Both the State and Central Governments supported the programme with subsidies. Solar Photovoltaic (SPV) Power Plants and Wind Mills began to emerge as the two alternate energy sources to generate power in Kerala. When Wind Mills were commissioned in the state it was noticed that the terrain is not at all suitable for installing large wind farms. Moreover power evacuation arrangements need to be strengthened to install more wind farms

There is a large potential available in Kerala for generating solar power using unutilized space on rooftops and wastelands around buildings. Small quantities of power generated by individual households, industrial buildings, commercial buildings or any other type of buildings can be used to partly fulfill the requirement of the building's occupants and surplus, if any, can be fed into the grid. This is possible, if the distribution company of that area is willing to allow power to be fed into the grid and has the necessary arrangements including availability of meters. In order to utilize the existing roof space of buildings, the roof-top SPV systems on buildings can be installed to replace diesel gensets installed for minimum load requirement for operation during power outages.

In these circumstance the State of Kerala looked forward to Solar PV Power Plants. Initially Off-Grid PV power plants were largely promoted by ANERT, the State Nodal Agency under Dept. of Power which is one of the dedicated State Nodal Agencies under the Ministry of New and Renewable Energy (MNRE), Govt. of India. The codes for installation of On-grid PV Power Plants are being formulated for the State and will be announced shortly. ANERT conducts the Pre-feasibility study for the project and based on the study prepares the Detailed Technical Specifications based on site requirements. Technical specification of a power plant has to be evaluated before commissioning.

Policies are being formulated for implementing On-Grid PV Power Plants in the State. For this, the standards of the Grid have to be set. The protective relay set points, voltage fluctuation limits, frequency standards, fault relay set points, voltage imbalance, harmonics, islanding issues etc. are some of the points to be highlighted for technical evaluation. Grid standards are to be complied before giving connection to the KSEB's Grid.

The cost of solar power at present is a little higher than the tariff charged from consumers by DISCOMs in most cases. However, if we take into the account the average tariff for consumers in the next 20 years and look at the cost for next 20 years, it can very well be seen that power generated from solar plants installed today would be cheaper than the average tariff for consumers in the next 20 years.

If we consider capital subsidy (up to 30%) also, it may be possible to generate power at Rs. 5 - 6 per kW for the next 20 years. This electricity would be cheaper than the diesel genset based electricity and if depreciation benefits are also available the cost will further come down. If a large number of rooftop solar installations are clubbed together into one and a single developer or system integrator is given an order of more than 5 MW, the cost per kW can be brought down to about Rs. 80,000 - 90,000.

2. Rooftop grid interactive SPV system

In grid interactive rooftop PV systems or small SPV system, the DC power generated from SPV Array is converted to AC power using Power Conditioning Unit and is fed to the Grid either of 33 kV/11 kV three phase lines or of 415/240 volt three/single phase line depending on the capacity of system installed at the institution/commercial establishment or residential complex. They generate power during the day, which is utilized fully by powering captive loads and feed excess power to the grid as long as grid is available. In case, where solar power is not sufficient due to cloud cover etc., the captive loads are served by drawing power from the Grid. The Grid-interactive rooftop system can work on net metering basis wherein the beneficiary pays to the utility on net meter reading basis only. Alternatively two meters can also be installed to measure the export and import of power separately.

Ideally, grid interactive systems do not require battery back-up as grid acts as the backup for feeding excess solar power and vice-versa. However, to enhance the performance reliability of the overall systems, a minimum battery back-up of one hour of load capacity is recommended. In grid interactive systems, it has, however to be ensured that in case the grid fails, the solar power has to be fully utilized locally feeding to the grid (if any, in excess) and stopped immediately so as to safeguard any grid person/technician from getting shock (electrocuted) while working on the grid for maintenance etc. This feature is termed as 'islanding protection'. The schematic diagram of the solar PV grid connected rooftop system is given in Figure 1.

3. Standards for Grid Connectivity, Operation and Safety Requirements

The suppliers of Solar Photo Voltaic Power System shall comply with the standards prescribed by International Electrotechnical Commission (IEC) and shall be certified by MNRE approved test centers. In the absence of Nation specific standards, IEC or IEEE 1547 Standard Series 2008 for Interconnecting Distributed Resources with Electric Power Systems may be generally followed in addition to the requirements specified in the CEA Regulation for Distributed Generation (2013).

The first priority, while considering the grid interconnection of a PV or Hybrid system, must always be the safety and reliability of the transmission and Distribution System. The Solar PV generation and interconnection technologies currently available are new and still evolving. Until significantly more experience is gained on how distributed solar generation impacts the system, it is better to be conservative and err on the side of caution while evaluating the system for providing grid interconnection.

Although line workers are trained to isolate, test, and either treat lines as live or ground all lines before working on them, these precautions do not alleviate all safety concerns because there are risks when these practices are not universally followed. With the pressure to repair a faulty line — or multiple lines — and restore customer service, skipping just one step of the isolate, test and ground procedure could be fatal. Accordingly, without the proper safety procedures and equipment in place, a large number of SPV systems scattered throughout a distribution system raises legitimate concerns for Board's line workers.

While finalizing the interconnection requirement for any particular PV installation following issues has to be kept in mind:

1) Solar PV System operation does not cause harm or damage to the Grid.
2) Solar PV System operation does not cause problems for other consumers on the local distribution system.
3) Most importantly, the safety of personnel and the public is not jeopardized by the operation of the interconnected Solar PV System.

4. SPV Grid-connected Rooftop World-wide

Germany, USA and Japan are leaders in adopting grid-connected SPV rooftop systems.Germany has highest PV installed capacity of 33 GW out of which 70 per cent is in rooftop segment (as on 31.03.2013). Italy has 12.7 GW PV installations with over 60 per cent rooftop systems. In Europe, of the total 50.6 GW PV installation, over 50 per cent is in the rooftop segment. Feed-in-tariff is the norm in Europe, while net-metering is popular in USA. In the USA, net metering is operational in 43 States but specific rules defer from State to State. The Energy Policy Act 2005 mandates all public electricity utilities to make Net metering options available to all customers.

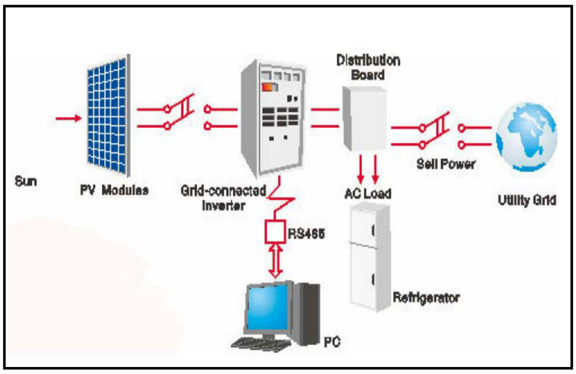

Fig .1: A typical Grid connected rooftop PV System

California has maximum installed onsite customer generated solar capacity of 991 MW with 1,01,284 net metering consumers from 115000 sites.

5. SPV Grid Connected Rooftop in India

Andhra Pradesh, West Bengal, Gujarat, Karnataka, Tamil Nadu, Uttarakhand, Uttar Pradesh and West Bengal have initiated actions for promoting the SPV Grid connected rooftop projects. In West Bengal, Grid connected rooftop is allowed only for institutional consumers with 2-100 kW size. Connectivity is allowed at low or medium voltage (6 kV or 11 kV) of distribution system and solar injection is permitted only up to 90 per cent of annual electricity consumption. Net energy supplied by the utility will be billed as per existing slab tariffs and the solar generation will offset consumption in the highest tariff slab and then the lower slab. As per recent policy all existing and upcoming commercial and business establishments having more than 1.5 MW contract demand to install SPV rooftop systems are required to meet at least 2% of their total electrical load. All existing and upcoming schools and colleges, hospitals, large housing societies, and government establishments having more than 0.5 MW contract demand are required to install SPV rooftop systems to meet at least 1.5 per cent of their total electrical load. The Policy targets 16 MW of rooftop and small PV installations by 2017.

In Gujarat, Gandhinagar city has initiated a 5 MW (4 MW in government buildings and 1 MW in private homes) rooftop PV programme based on Feed-in-Tariff /sale to utility. Two project developers for 2.5 MW each have been selected through reverse bidding with GERC cap of Rs. 12.44/kW. One developer will buy from developer @ Rs. 11.21/kW for 25 years and the second developer will pass on Rs. 3.0/kW to rooftop owner as roof rent. Recently 5 more cities—Bhavnagar, Mehsana, Rajkot, Surat and Vadodara have started installing pilot rooftop projects.

In Karnataka, as per new RE policy 2009-14, the State will promote rooftop with net metering. System size to be 5-100 kW and interconnection at 415 V, 3 phase or 11 kV have been allowed. Maximum energy injection allowed is up to 70 per cent of energy usage at site from DISCOM. Energy injection will be settled on net basis in each billing period, no carry forward is allowed.

In Tamil Nadu, as per 'State Solar Policy 2012' 350 MW SPV rooftop has been targeted during 2012-2014. Net metering will be allowed at multiple voltage level. The interconnection will be as follows:

< 10 kW	- connection at 240 V
10 to 15 kW	- connection at 240/415 V
15 to 50 kW	- connection at 415 V
50 to 100 kW	- connection at 415 V
100 kW	- connection at 11 kV

Exemption from payment of electricity tax will be allowed for 5 years for 100 per cent solar electricity used for self/sale to utility. All new government/local body buildings shall necessarily install PV rooftops.

In Chandigarh, about 3.0 MW projects of SPV grid connected PV rooftops projects have been sanctioned for the model solar city which are under installation of which 150 kW have been commissioned. Discoms has agreed to purchase power and the rates are being finalized.

Solar Energy Corporation of India has been entrusted with the execution of 16.6 MW plants by the Ministry in the country under the funding received from National Clean Energy Funds. The projects are under implementation.

Kerala Govt. has announced the State Solar Energy Policy recently. The policy discusses the stakeholders involved in the project, the procedures involved in setting up Off-Grid and On-Grid Solar PV Power Plants in the State.

6. Business models for rooftop and small scale solar power plants

For the success of smooth operation of rooftop and small solar power plants, various situations and conditions need to be worked out to make it a workable business model.

There can be many possible business models, some of which can be considered are as follows:

6.1 Solar installations owned by consumer

Solar rooftop facility owned, operated and maintained by the consumer(s).

Solar installations owned, operated and maintained by 3rd party

The 3rd party implements the solar facility and provides services to the consumers. The surplus electricity may be injected to the electricity grid. The combinations could be:

Arrangement as a captive generating plant for the roof owners:

The 3rd party implements the facility at the roof or within the premise of the consumers; the consumer may or may not invest as equity in the facility as mutually agreed between them. The 3rd party may also make arrangement of undertaking operation and of maintenance of the facility. The power is then sold to the roof owner.

Solar lease model, sale to grid:

The 3rd party implementing the solar facility shall enter into a lease agreement with the consumer for medium to long term basis on rent. The facility is entirely owned by the 3rd party and consumer is not required to make any investment in facility. The power generated is fed into the grid and the roof top owner gets a rent.

6.2 Solar installations owned by Discoms

In this model, the Solar installations will be owned by Dicoms.

Solar installations owned operated and maintained by the Discom:

The Discom may own, operate and maintain the solar facility and also may opt to sub contract the operation and maintenance activity. The Discom may recover the cost in the form of suitable tariff. The electricity generation may also be utilized by Discom for fulfilling the solar renewable purchase obligation.

Distribution licensee provides appropriate viability gap funds:

The Discom may appoint a 3rd party to implement the solar facilities on its behalf and provide appropriate funds or viability gap funds for implementing such facility. It may also enter into an agreement with the 3rd party undertaking the operation and maintenance of the solar facilities.

7. Prerequisites for promotion of rooftop and small solar plants

Feed-in-tariff: Since, the grid interactive rooftop and small solar plants have an impact on the revenue earnings of the Discoms, the provision should be made in such a manner that it provides a safeguard to all stakeholders including Discoms. The tariff should be such that it is attractive for the roof owner and does not put too much burden on the Discoms. Therefore regulators have to come up with feed-in-tariff for roof tops with and without MNRE subsidy.

Necessity of connectivity regulations: Central Electricity Authority (CEA) has notified "CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013". The announcement of such standards is providing necessary guidance to Discoms and also shall provide the transparency in the process and encourage consumers for installing such solar plants.

Availability of electricity grid: The availability of electricity grid near the solar installation is an essential component which needs to be provided by the concerned agencies.

Eligible capacity for participation: Eligible capacity limit needs to be specified in order

to avoid the grid congestion by the very small capacity solar plants.

Capacity building of Discoms: The Discoms staff needs to be trained to take up these

activities and should be favorably inspired.

8. MNRE scheme to promote grid interactive rooftop SPV system

The Ministry has been implementing a programme on "Off-grid and Decentralized Solar Applications" for the first phase of the Jawaharlal Nehru National Solar Mission (JNNSM) vides no. 5/23/2009-P&C dated 8th July 2010. The programme has been amended time to time and in the recent amendment, made vide ref. no. 5/23/2009-P&C (Pt.III) dated 30th October 2012, a provision on this ongoing scheme has been made to connect the small SPV plants with grid to export excess power. As per this amendment, the Para 3.2 in the aforesaid scheme may be amended to read as under:-

Para 3.2 "Various off-grid (including provision to connect with grid to export excess power) solar PV system applications up to maximum capacity of 100 kW per system and off-grid—grid and decentralized solar thermal applications to meet/supplement lighting, electricity/power, heating and cooling energy requirements would be eligible for being covered under the scheme. For mini-grids for rural electrifications, applications up to maximum capacity of 250 kW per site would be supported. Connection with grid will not debar from coverage under the scheme."

Suggested Modus Operandi by MNRE

The project site/rooftops at office buildings, commercial buildings, residential complexes etc., can be selected on the basis of the total energy requirement of the premise and the area available for installation of roof top solar PV system.

Solar PV system on the roof top of selected buildings can be installed for meeting the requirement of the building as much as possible.

Though rooftop systems shall be generally connected on LV supply, large solar PV system may have to be connected to 11kV system. Following criteria have been suggested for selection of voltage level in the distribution system for ready reference of the solar suppliers:

In up to 10 kW solar PV systems, low voltage single phase supply shall be provided.

Thereafter up to a level of 100 kW solar PV systems, three phases low voltage supply shall be provided.

In case load is more than 100 kW and does not exceed 1.5 MW, SPV system connection can be made at 11kV level.

In case load is more than 1.5 MW PV systems and does not exceed 5 MW, SPV system connection can be made at 11kV/33 kV/66kV level or as per the site condition.

Table 1: **Types of solar power plants and cost**

Sl. No	Type of System	Benchmark Cost(Rs/W_p)
1	Solar Power Plants/Packs (with battery, 6 hrs autonomy) > 300W to 1 kW	210
	> 1kW up to 10kW	190
	> 10kW up to 100 kW	170
2	Solar Power Plants/Packs (without battery) up to 100 kW	100
	>100kW up to 500 kW	90

MNRE may provide one time subsidy up to 30% of the benchmark cost of the project. The present proposed benchmark cost is given in Table 1 above.

A power purchase agreement (PPA) needs be signed between the owner of building, 3rd party and the DISCOMs as applicable. An agreement between DISCOM and the owner of building/premise/SPV plant needs to be signed for the net metering and billing on the monthly/bi-monthly basis as applicable. Suitable payment security mechanism is to be provided by the Discom/state nodal agency/utility.

9. Conclusion

Thus the SPV gird connected rooftop systems are being seen as the great future market in India. It can only develop if the distribution companies come out with a suitable mechanism for grid connectivity, power purchase agreements and the trade of solar electricity. The success of the programme lies with the grid parity price of solar electricity. With about 30% government subsidy, or even without subsidy it can be a win-win situation for both the players i.e., the end user and the DISCOM.

The issues related to operational aspects may not be that much relevant at a relatively sparse distribution of SPV systems in the grid in the initial stage, but can become a matter for consideration with higher proliferation of the systems. All the stake holders including Renewable Energy State Nodal Agencies, State Utilities, State Regulatory Commissions, Electrical Inspectorate authorities etc should act together to make this upcoming solar revolution a success.

Generation of Electricity from Organic Waste

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1. Introduction

In accordance with the fast growing population, the demand for energy and the discharge of waste are increasing day by day. To overcome the energy crisis, alternative energy sources are the only remedy. Generation of energy from waste is beneficial in many ways. It is most suitable for eco-friendly waste disposal and also for energy generation.

With a view to finding out a permanent solution to the problem of contagious diseases caused by the accumulation of waste that is being increased day by day it is quite necessary that we have to extend the scheme of implementation of decentralized waste treatment programmes all over the country. The biogas technology enables one to produce bioenergy in the households by treating the wastes generated in the houses. This technology is also made applicable for treating the wastes produced from public places like markets, slaughter houses, hotels, convents etc and for generating electricity without causing any pollution to the atmosphere.

2. Technology adoption for fast degradable materials

Through the utilization of Biogas Technology (Biomethanisation) for decentralized waste management, the collection, transportation and segregation of waste can be totally avoided as the wastes are treated at source itself.

3. Biomethanisation Technology

Biomethanisation is a universally accepted and proven technology for Bioenergy Generation from bio waste. It is very simple, user friendly and it needs no recurring expenses. Through the adoption of biomethanisation technology all degradable waste can be treated with the help of different types of anaerobic bacteria / microbes in a concealed chamber / digester. Treated biomaterials, coming out from the digester in the form of liquid or semi liquid can be used as a very good bio manure / organic fertilizer.

4. Generation of Electricity from Biogas

The main advantage of waste to electricity project is that no external power is required for the operation of the plant. The power generated in the treatment plant can be utilized to meet the in-house requirement completely. Excess quantity can be utilized for any type of application, like the street lighting, providing lights to the markets etc.

Normally, 1.5 kw elctricity can be produced from one cubic metre of biogas. Depending upon the percentage of methane content in biogas, the power generation may slightly vary. The size of the generator can be fixed depending upon the availability of gas, the quantity of gas and the duration for the requirement of the power. The gas can be utilized as operation fuel in generators. Before feeding biogas as the fuel in generator the gas has to be passed through a gas scrubber to remove unwanted particles, gases, moisture etc.

There are two types of generators used for generating electricity from biogas. One is the duel fuel model and the other is 100% biogas model. Duel fuel models are diesel gensets. In this system the biogas is connected to the generator through air mix. Once the biogas is passed through the generator, automatically consumption requirement of the diesel is reduced. Normally duel fuel generators are working in 80% - 20% mode.

In 100% biogas engines no other fuel is required either for starting or for operation. Any type of petrol engine can be modified for operating the same using biogas as operation fuel. The imported models of 100% biogas engines are very costly and the maintenance of such systems is very expensive. These engines are installed in various projects and the performance of all of them is very good.

5. Operation of Waste to Electricity Plant

The biowaste generated in fish & vegetable markets, slaughter houses etc. are collected in separate bins which are carried to the treatment plant site. After final sorting, easily degradable biowaste is allowed to pass into the digester/ reactor. Slow degradable materials are fed in to the pre-digester and the treated slurry is mixed with this feed material every day. The leachate from the pre-digesters is extracted through specially designed filters and channelized to the digesters for biogas production. The organic waste thus fed into the plant decomposes within days through anaerobic process and the methane gas generated is collected in the gas holder of the plant. For the effective operation and long life of generators, the gas generated has to be purified before utilization. For eliminating H_2S, unwanted dust and moisture content, this gas is allowed to pass through filters and gas scrubbers. After filtration it is channalized to the generator for electricity generation. Electricity thus generated from the plant is utilized to meet the in-house requirements and for street lighting. The treated bio waste can be collected from the pre digesters and this can be utilized as biomanure.

6. Bio manure

The treated biowaste materials coming out from the digester is in the form liquid or semi liquid. This is a very good fertilizer for all types of plants. This can be mixed with equal or more quantity of water and directly be applied to plants. The solid manure from this slurry can be separated through the filtering process. Filtered liquid can be utilized and kept as solid fertilizer for later use. Treated solid biomanure can also be collected directly from the pre-digester .The biomanure generated through the biowaste treatment is a better substitute of chemical fertilizer. Through the utlisation of this, Lakhs of rupees spent for purchasing chemical fertilizers can be saved to a great extent. The growth ratio of plants will be highly improving with in a short period through the use of bioliquid fertilizer. The resistance power of plants from the insects is will also be improved. In short the treated slurry can be called as a tonic of plants. The water storage capacity of the soil will be improved through the application of solid biomanure. The presence of insects in the soil can also be avoided to an extent.

7. Types of wastes that can be treated under Biomethanisation Technology

All easily degradable materials including cooked and raw food wastes, fruits and vegetable waste, fish and meat waste, excreta of all domestic and wild animals and birds and waste water containing bio waste materials can be treated with this technology. Slow degradable materials like vegetables, green or wet plant parts can also be treated with this technology, using specially designed pre-digesters

8. Main parts of a Waste to electricity Plant

Digester ,Gas Collector , Anaerobic Pre digester ,Slurry loop system, 100% biogas generator, Standby generator, Biogas scrubber ,Dehumidifier, Control panel , Power distribution system, Excess Gas reservoir.

9. Waste to electricity project –Success stories from Kerala

BIOTECH – Kerala started functioning from 1994. The main activities of BIOTECH from the very inception of the organization include promotion, implementation, training, R&D, and also the creation of awareness to the people in the field of conservation of renewable energy by waste management.

The installation of Kerala's first bio waste treatment power generation plant at Pathanapuragm Grama Panchayat in the Kollam District was 10 years back. This plant is treating 500 Kg of organic waste every day and generating 40 kw electric power every day. After the successful completion of the above project, 52 Grama Panchayats in Kerala State came forward for the installation of such plants and BIOTECH had completed the installation of the power generation projects using market / slaughter house waste with power generation capacities ranging between 3 kw to 20 kw. The power generated from these projects is being utilized for energy requirements of the concerned markets and to meet the in-house requirement of the plant. The main components of the waste to electricity plant -100% biogas engines filters and gas scrubbers and the pre-digester are developed by BIOTECH

Advantages of BIOTECH Waste to electricity projects

1. There is no need of grid electricity for the regular operation of the plant. A part of the power

generated from the plant is utilizing to meet the in-house requirement of the plant.

2. No much moving parts or complicated machineries.
3. Introduction of anaerobic pre digesters helps to treat the waste completely and to collect the treated waste. It prevents the scum formation tendency of the plant. The inbuilt slurry loop systems accelerate the fermentation process and reduce the consumption of drinking water. As per of the treated slurry is selling as liquid organic fertilizer.

10. Waste to Energy

Different models of plants for the treatment of waste, according to the requirement of the consumers and nature of waste, have been developed by BIOTECH. These models cater to the needs of different categories of beneficiaries such as domestic households, public institutions like hospitals, schools, hostels, convents etc. and also Local Body establishments like Panchayats, Municipalities, Corporations etc. for treating different types of waste. BIOTECH has successfully installed around 30,000 family size plants with the financial assistance from MNRE,Govt of India, and with the active co-operation of the local bodies.

In recognition of our selfless services to the society BIOTECH was honored by conferring on it the prestigious International Ashden Award "GREEN OSCAR 2007".

11. Conclusion

If similar decentralized waste treatment plants are installed all over country, it would be very helpful for the production of biogas, electricity and also bio manure apart from treatment and disposal of unwanted waste. The similar projects may be implemented all over the country with the cooperation and support of all concerned.

Dr. A. SAJIDAS is recipient of several national and international awards including WINNER OF GREEN OSCAR (INTERNATIONAL ASHDEN AWARD-2007) FOR GENERATION OF ENERGY THROUGH DECENTRSALIZED WASTE TREATMENT From UK, Presented by Al Gore, American Vice President (Former) in the presence of Prince of Wales - Prince Charles.

He holds a Masters Degree (MA) in Sociology and Doctorate in Solid Waste Management and has experience of more than 29 Years in designing and execution of various models of Waste to Electricity Biogas plants, other Renewable energy projects, Waste management projects and Energy conservation activities. He has in his credit 22 Important Inventions relating to the development of various green energy projects. Presently working as the Managing Director, BIOTECH, Trivandrum and an International Consultant-Biogas in the Ministry of Agriculture, Republic of Yemen under the project funded by the World Bank and Government of Japan.

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Renewable Energy Project

Operational Issues of Pricing Schemes for Renewable Energy

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Abstract—**Electric power generation using consumer-owned grid-connected solar photo-voltaic system is increasing significantly at the domestic level. As the penetration levels of renewable energy sources rise in the domestic sector, there may be time periods of power flow from the households into the grid during a day. Traditional pricing schemes find difficulty to be implemented in such a situation of bidirectional energy flow and face operational challenges in the implementation because of the intermittent characteristics of renewable energy sources. The paper focuses on the operational issues of traditional pricing schemes and the role of dynamic pricing schemes in domestic level situations with the large scale integration of renewable energy sources.**

Keywords — **Renewable energy, dynamic pricing,**

I. INTRODUCTION

Residential electrical power generation using consumer- owned, grid connected solar photovoltaic systems has become an attractive proposition for many households. The use of renewable energy sources in the household results in bidirectional energy flow from the consumer side to the grid in the distribution system. The locational and temporal characteristics of renewable energy sources cause forecasting and operational challenges in the implementation of traditional pricing programs[1]. Furthermore the complexity of traditional pricing schemes increases with the addition of suitable mechanism for storage, processing and transmission of information to various parties in a grid structure with large number of intermittent renewable energy sources. The pricing framework in a restructured power system has to process a large amount of transactions with the integration of distributed generation into the power grid.

II. OPERATIONAL CHALLENGES

Net metering, Time-of-Use Pricing (TOU), Critical Peak Pricing (CPP), and Real Time Pricing (RTP) are some of the existing pricing schemes all around the world. The modes of operation of these pricing schemes are given in Table 1. As presented in Table 1, each pricing scheme differs in its period of prediction, price blocks and price pattern. Net metering has become a wide spread policy to support the integration of distributed photovoltaic (PV) and wind power generator. The fixed tariff structure is adopted in this scheme. In the net metering, consumers make use of power generation from solar

PV and wind generators for their own consumption and the excess power generated are fed to the utility grid. They will continue to draw their power requirement from the grid as required. At the end of the billing period, excess energy fed into the grid will be deducted from the power supplied by the utility, and the net consumption will be charged at retail tariff slabs [2]. In this approach, there is no actual financial transfer from the utility to the consumer, who is benefitted through an offset of marginal consumption. An alternative of net metering is the monthly netting option, where by PV production can offset up to 100% of consumer usage within each month and the excess PV production at the end of the month is compensated at the prevailing market rate. The drawback of net metering scheme is that the value of bill savings it provides to consumers with PV depends heavily on the structure of the underlying retail rate, as well as the characteristics of PV system. Consequently, the bill savings value of net metering may vary substantially from one consumer to next. Additionally, net metering scheme is not dynamic so that the scheme cannot support consumer oriented demand side management strategies. Real time pricing programs are suitable to accommodate incentive for consumers to respond load management programs

Under RTP rate, consumer's marginal retail rate can change every hour and is tied to wholesale market prices [3]. Time of Use (TOU) scheme is one where price is fixed in advance for a long period and under a fixed timetable. The price level is set based on long term cost predictions. TOU pricing typically sends a pricing scheme which applies over a longer time period, although the length of the price blocks is shorter.

Table 1: Modes of operation

Tariff scheme	**Forecasting**	**Price pattern**	**Price block**
Net metering	Nil	Month	-
Time-of-use	days	Year/ season	>1 block/ day
Critical peak pricing	<1 day	Hours	Hours
Real-time pricing	<1 day	1 h	1 h

In critical peak pricing, a peak price is added on top of another pricing scheme during a limited amount of hours a year. The deployment of these pricing schemes for residential users is limited. Some of the reported works in this area are given here. A day ahead real time pricing model is presented in [4], which can assist a retail energy provider to offer optimal day ahead hourly pricing using smart metering. The economic incentive for consumers to respond to hourly changes in electricity price is considered in the work. In US, an hourly RTP scheme is used which charges consumers based on its hourly wholesale prices [5]. The electricity rate of real time pricing is decided based on the forecasted capacity of demand and generation over a given time period. The above pricing schemes become more complex when location and time effects in renewable energy generation come into play for the following reasons (i) The variations of power output are not known ahead of time. (ii)The characteristics of new small resources are not standardised, and the system operators do not have ready to use models and parameters. This necessitates complex forecasting engines and a mechanism for large scale time series data management. Here, the handling and processing of large-scale data are really an operational challenge.

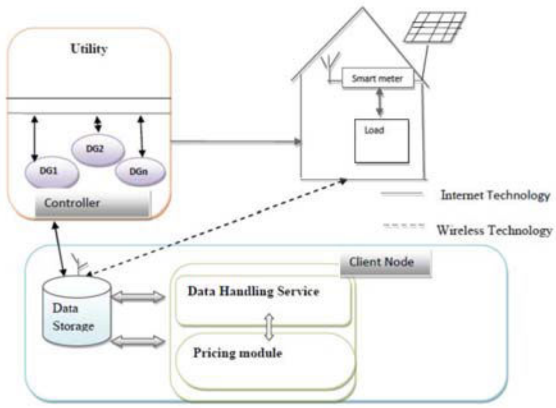
Dynamic pricing schemes are getting attention for application to residential consumers. In contrast to traditional tariffs, dynamic pricing schemes allow for more variability in the price level during a day. The price in a dynamic pricing scheme is subject to multiple factors such as location, time, energy usage and generation level.

The dynamic pricing programs are intended for renewable energy promotions as well as they act as a driver for various demand side management operations. Demand side management program like load shifting has become an active topic with the increased integration of rooftop solar PV and wind generators in the domestic sector. Load shifting operation enables effective utilization of resources with minimum storage measures in a grid structure with large number of renewable energy sources [6]. Pricing becomes a key factor in an interactive strategy for grid interaction and optimisation. The paper [7] investigates the implementation of price based demand response by industrial consumers to increase their proportional use of wind generated electricity by shifting their demand towards times of low prices. In order to support price responsive demand management programs, much more significant deployment of metering (smart meter) and storage measures are required. The use of smart meter results in a huge amount of data transfer, because the measurement of the demand and generation is performed on a timely basis. To handle these data and the demand side management operations, a suitable platform that is, capable of storing a significant amount of data, and has fast processing capability with good computational facilities is required.

III. The proposed architecture for dynamic pricing

The utility's concerns, when real-time pricing is applied in domestic sector are to monitor and verify the process adequately and the coordination and processing of the time series data from remote locations. The pricing programs require intensive monitoring and storage of the consumer's power consumption and generation levels [8]. The real time mode operations in the pricing scheme involve secure and reliable exchange of information, coordination and processing of data from remote locations. Processing large amount of data at a sustained rate is a challenge. Coordination, monitoring and verification of time varying parameters associated with the renewable energy integration into the grid structure are other challenges that are to be addressed. The execution of the pricing program in domestic level situations with large-scale integration of renewable energy sources will lead to more internet based information exchange among system operators and other entities in a power system. In these scenarios, dynamic pricing scheme using real time data in a cloud computing framework is proposed to reduce the difficulties due to operational issues. The information flow for the required dynamic pricing is depicted in Fig 1. Data handling service is meant for manipulations of generation and consumption data from various generating sources and loads. Computation of electricity price of consumer on time basis is carried out by the pricing module.

Fig.1 Required information exchange for dynamic pricing



IV. conclusions

The energy pricing and price based demand side management programs in a domestic level situation with the integration of renewable energy sources require a platform for online, offline computations, monitoring and analysis of large data. The application of cloud computing technology will provide substantial support for the storage and distributed processing. The dynamic pricing scheme is flexible to provide pricing variations on the basis of energy flow, which will encourage consumers for new capacity installations of renewable energy sources that potentially lead to several economic and environmental advantages.

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Failure of Distribution Transformers due to Harmonic Pollution

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Abstract

Transformers are critical equipment in a power system. Failure of transformers affects the reliability of power supply. Life of a transformer is determined by the maximum temperature rise inside the transformer. Harmonic pollution caused by non – linear loads is one of the factors which cause additional heating in the transformers. In this paper, the harmonic pollution caused by different non – linear loads is analysed. The Hot Spot Temperature Rise produced by different types of loads is also presented.

1. Introduction

Transformers are expensive equipment in the power system. Determination of life of transformer is very critical as damages in a transformer cause long interruption of power supply. The life of a transformer is determined by the life of the insulation which in turn is assessed by the maximum temperature rise inside the transformer. The factors which affect the transformer life include harmonics, faults, surges, poor design, lack of regular maintenance etc. Now a days, all power utilities are much worried due to the unusually high rate of failure of distribution transformers in service.

Condition monitoring techniques can be used to assess the condition of a transformer. Different condition monitoring techniques include Dissolved Gas Analysis, Furan Analysis etc. Condition of a transformer can also be assessed by analyzing the temperature distribution inside the transformer.

Heat is mainly produced inside a transformer due to the passage of load current through the resistance of the winding conductors (load loss), and due to heat production in the magnetic core (no-load loss). Additional but less significant sources of heat include eddy current heating in conductors and support steel structures, and dielectric heating of insulating materials. The I^2R loss depends on magnitude of the harmonic distortion and is independent of its frequency. The winding eddy current loss is affected by the frequency and the magnitude of the current. Transformer thermal design is aimed at removing the generated heat effectively and economically so as to avoid deterioration of any of the components of the transformer due to excessive temperature.

In practice, all parts of a winding are not operated at the same temperature since some parts are cooled more effectively than others. The part of the winding which reaches the hottest temperature is known as the 'hot spot'. The rate of deterioration of the winding insulation increases as the conductor temperature increases. Hence, it is necessary to know the hottest conductor temperature inorder to ensure a reasonable expected life for the insulation and the transformer.

The failure of a transformer is caused either due to reasons within the transformer or due to operational hazards. Majority of the failures ie; 72 % get precipitated as winding failures. Out of which, nearly 54% manifest as HV winding failures, 7% as LV winding failures, 11% as failures of both, 6 % due to oil leaks and the remaining due to other reasons. These may be due to various electrical and mechanical reasons. The other faults include faults in the transformer bushings, tap changers etc. Failure rate of transformers is high in certain month or period. This is due to the change in atmospheric conditions and related changes in loading pattern.

As more faults occur in the HV windings of distribution transformers, the reasons are to be analysed. The faults in HV windings may be due to lightning, harmonics etc. In this paper, the harmonic distortion caused by different non-linear loads is analysed.

2. Sources of harmonics

Harmonics are non-fundamental frequency components of a distorted power frequency waveform. The principal effect of non-sinusoidal voltages on the transformer's performance is the generation of extra losses in the core. Non-sinusoidal currents generate extra losses and heating of conductors, enclosures, clamps, bolts etc. Increased losses reduce the efficiency of the transformer and accelerate the loss of life of the insulation due to the additional heating of the windings. A detailed review on power quality issues, standards and useful guide lines can be seen in Edward Reid [1].

Small commercial and office building power systems are largely composed of single phase loads which are often fed from a 4-wire, wye grounded source. Personal computers, printers, copiers and most other single phase electronic equipment employ switch - mode power supplies (SMPS). Switch - mode power supplies use dc to dc conversion techniques to achieve a smooth dc output with small light weight components. The key advantages are light weight, compact size, efficient operation and lack of need for a transformer. Switch-mode power supplies can usually tolerate large variations in input voltage. A distinctive characteristic of switch-mode power supplies is a very high third harmonic content in the current.

Single phase devices generally exhibit the following harmonics of the fundamental in the current waveform: 3, 5, 7, 9, 11, 13 etc. Even with balanced load conditions, harmonics which are multiples of three will add in the neutral conductor. Due to the potentially high neutral currents in such a situation, a common neutral conductor may be rated as much as double the phase conductors or separate neutrals may be run on each phase.

Large commercial and industrial power systems are mostly composed of three phase loads. The current harmonics are the odd harmonics except for multiples of three (5, 7, 11, 13 etc.). The third-harmonic neutral-current problem is generally not a consideration in these applications. But, here also, additional heating is produced due to the harmonic currents. The additional heating caused by harmonics requires load capability derating to remain within the temperature rating of the transformer. Therefore it is of utmost importance to estimate the loss due to these distortions and study its impact on the life of the transformer.

There are three effects that result in increased transformer heating when the load current includes harmonic components:

- RMS Current : Harmonic distortion increases the transformer rms current which in turn results in increased conductor losses.
- Eddy current losses : These are due to induced currents in a transformer caused by the linkage of magnetic fluxes. These induced currents flow in the windings, in the core, and in other conducting bodies subjected to the magnetic field of the transformer and cause additional heating. This component of transformer losses increases with the square of the frequency of the currents.
- Core losses: Increase in voltage distortion may increase the eddy currents in the core laminations. The increase in these losses due to harmonics is generally not as critical as the previous two.

Transformer winding connections have a significant impact on the flow of triplen harmonic currents from single phase non linear loads. Supply transformers which are connected delta-wye grounded will block most of the third harmonic current and its multiples from flowing into the higher voltage system. But the triplen harmonic currents circulate in the delta winding and cause additional heating in the High Voltage winding of the distribution transformer. Measuring the line currents on the delta side of such a transformer will not show the triplens and therefore, do not give a true idea of the heating of the transformer [2].

Details of faulty transformers were collected from the Transformer Maintenance and Repair (TMR) Division, Thirumala for a period of one year (January 2006 – December 2006). It was observed that out of 190 failures reported, 154 failures (81%) were in HT coils (delta winding). The remaining failures were due to faults in LT coils, oil leaks etc. Main reason for the burning of HT coils could be due to the presence of triplen harmonics caused by the increased non- linear loads on the end use side.

Taheri et al. [3] presented a finite element method that could predict the field distribution on the transformer components and also employed dynamic thermal model and IEEE guide lines for the calculation of hot spot and top oil temperature under harmonic conditions. The results showed that as the harmonic current increases the hot spot and top oil temperature increases and decline the life span of the transformer.

3. Harmonic Distortion produced by different lamp loads

The harmonic pollution caused by different lamp loads was observed in the laboratory using a power quality analyzer. Fluorescent tubes (FT) with electromagnetic as well as electronic chokes and compact fluorescent lamps (CFL) of different types were tested. Table I shows the Total Harmonic Distortion (THD) and % of third harmonic currents produced by these lamp loads.

Table I: Harmonic Distortion produced by different lamps

Type of load	%THD	% ofThird Harmonics
CFL (Brand A)	77.1	56
CFL (Brand B)	75	47.2
CFL (Brand C)	71.5	52.5
CFL (Brand D)	69.9	53.4
FTL (with electromagnetic choke)	8.5	6.3
FTL (with electronic choke)	72.2	36.7

Table-I shows that CFLs of different makes and FT with electronic choke produce more harmonic distortion and also they draw large amount of third harmonics.

4. Harmonic Pollution in an IT Industry

To study the effect of non-linear loads on the temperature rise of transformers, a distribution transformer installed in a software company is analysed. The transformer selected was that at NILA, Technopark, where harmonic pollution is severe. The ratings of the transformer are given in Table II:

Table II: Rating of the Distribution Transformer

Three phase distribution transformer	
Transformer	Dry Type
kVA	1250
Voltage : HV	11,000 V
LV	433 V
Current : HV	65.6 A
LV	1666.7 A
Phases	3

Online measurements were also taken using power quality analyzer and the observations are given in Table III :

Table III: Measurements taken from the Distribution Transformer

Time	Line	kA	THD(%) -I	DF
11.55 AM	1	1.018	8.5	-
	2	1.032	8.9	-
	3	1.013	8.4	-
	N	0.088	-	71
12.50 PM	1	1.042	8.3	-
	2	1.02	9.3	-
	3	1.013	8.7	-
	N	0.075	-	81.6
1.25 PM	1	0.977	9.5	-
	2	0.948	9.5	-
	3	0.952	10.6	-
	N	0.076	-	76.8

Table shows that the % THD is above the limits and the neutral current is very large. Distortion Factor (DF) gives a measure of harmonic distortion in the neutral current. The frequency spectrum of the neutral current of the transformer is shown in Figure. 1.

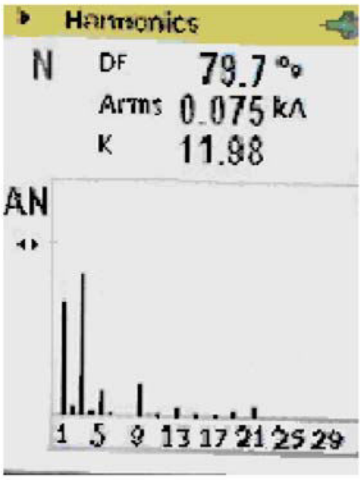


Figure. 1 Frequency spectrum of neutral current of the transformer

From the figure it is clear that the neutral current has a high component of third harmonics.

Table IV shows the load current, ambient temperature and winding temperature (WT) during different hours of a day, (15-04-2009).

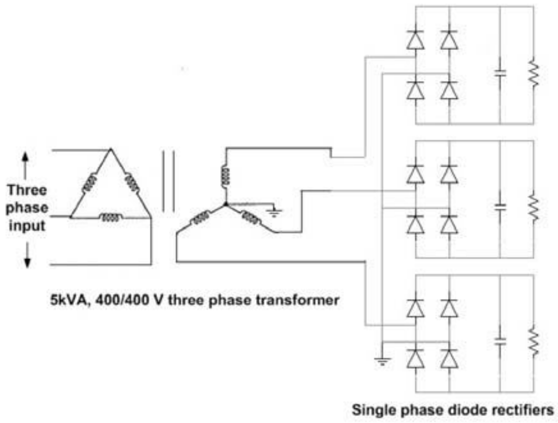
Table IV: Variation of HST with Load Current and Ambient Temperature

Time (hours)	Load Current (A)	Ambient Temperature (^{0}C)	Winding Temperature (^{0}C)
9.00	41	29.7	82
10.00	42	31	108
11.00	45	31.4	110
12.00	44	32.9	118
13.00	42	32.8	119
14.00	42	33.5	117
15.00	41	33.1	116
16.00	41	32.7	116
17.00	35	32	109
18.00	31	31.1	99
19.00	29	30.5	86
20.00	24	30.2	80
21.00	22	29.9	78
22.00	16	29.8	70
23.00	16	29.6	69
24.00	14	29	65
1.00	14	28.7	60
2.00	13	28.7	58
3.00	13	28.2	58
4.00	13	28.1	57
5.00	13	28.1	59
6.00	12	27.7	58
7.00	13	27.7	58
8.00	13	28.4	68

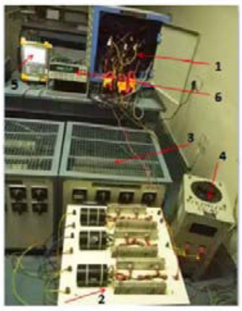
The permissible maximum temperature of the winding is 115 ^{0}C. But it is seen from the Table that when the load current is 41A and the ambient temperature is 32.7^{0}C, the winding temperature is 116^{0}C. That is; the loading of transformer is limited to 62.5% of rated load. The main reasons for this reduced loading are harmonics and increased ambient temperature[4].

5. Experimental setup

In order to study the effect of non-linear loads on heating of transformer, a prototype transformer is connected to both linear and non-linear loads. The 5kVA, 400/400V three phase dry type transformer considered in this study consists of core, primary windings (250 turns) and secondary windings (144 turns). The core is made of silicon steel and windings are made of copper. The primary windings of the transformer are connected in delta and secondary windings in star. The transformer is connected to linear (resistive) as well as non linear load (single phase diode rectifier and three phase diode rectifier). Figures 2(a) and 2(b) show respectively the schematic diagram and the photograph of the experimental set up of the transformer connected to a single phase rectifier load. The input voltage to the transformer is varied by means of a three phase autotransformer. The voltage, current and harmonic distortions are measured using power quality analyser. The temperature in the windings and the core of the transformer is measured by fixing K type thermocouples at different locations in the transformer. All the thermocouples are connected to a Personal Computer based Data Acquisition system. The same arrangement is made when the transformer is connected to the three phase rectifier load and this is depicted in Figs. 3(a) and 3(b) respectively.

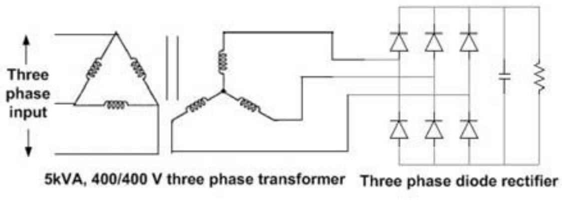


(a) Schematic Diagram

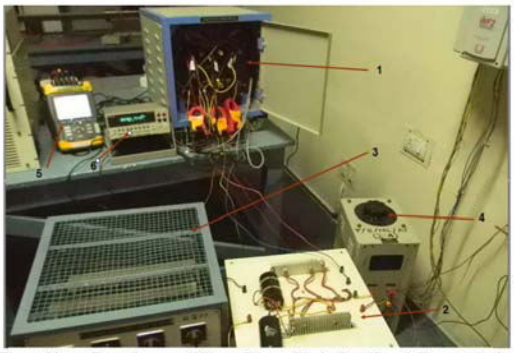


1-Three Phase Transformer, 2-Single Phase Diode Rectifiers, 3-Rheostatic Load, 4-Autotransformer, 5-Power Quality Analyzer, 6-Data Acquisition System

Figure. 2. Transformer connected to single phase diode rectifier load



a. Schematic Diagram



1-Three Phase Transformer, 2-Three Phase Diode Rectifier, 3-Rheostatic Load, 4-Autotransformer, 5-Power Quality Analyzer, 6-Data Acquisition System

b. Photograph

Figure. 3. Transformer connected to three phase diode rectifier load

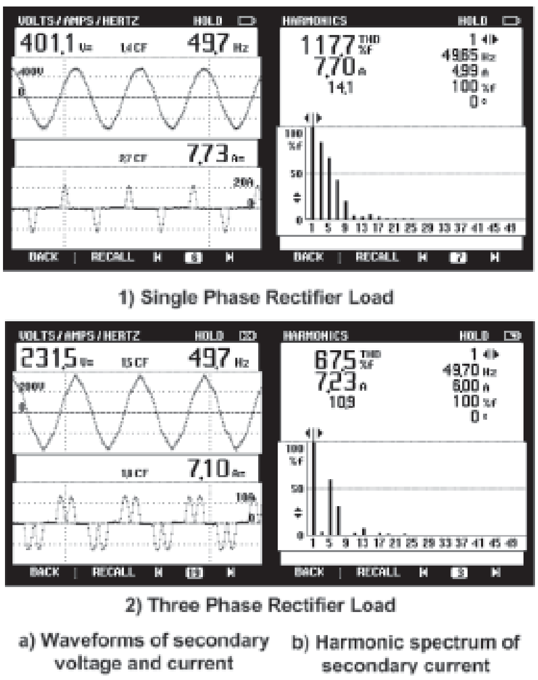


Figure 4 Waveforms and harmonic spectrum

Figure-4 shows the harmonic spectrum of the secondary current obtained from experiments when the transformer is connected to single phase and three phase rectifier loads. It is seen that the harmonic distortions produced by non - linear loads are very high. The presence of harmonic currents increases the losses of the transformer and produces additional heating.

Table V: Variation of HST with different load

Type of load		Load (A)	%THD	Rise in HST (^{0}C)
Linear	Resistive	7.77	3.6	79.8
Non-linear	Three phase diode	7.77	67.5	92.9
	Single phase diode	7.77	117.7	96.2

Table V shows the variation of the rise in HST of the transformer when subjected to linear as well as non-linear loads. It can be inferred from the table that rise in HST increases with increasing harmonic distortion and this increase in HST is more significant when transformer is connected to a single phase rectifier. This is because when single phase rectifier load is connected the triplen harmonics are predominant and these triplen harmonics add up in the neutral and reflects in the primary delta winding, causing additional heating in the transformer.

6. Conclusion

In this paper, a brief description of the sources of harmonics in residential and commercial buildings is given. The effect of harmonics on the losses of distribution transformer is also discussed.

To study the effect of different types of lamps on power quality, the harmonic distortions produced by different lamps are measured. It is found that lamps manufactured by different companies produce different harmonic distortions. It is also observed that the harmonic distortion produced by fluorescent tubes fitted with electronic choke is more severe.

Online measurements are taken from a distribution transformer installed in a harmonic polluted environment. It is observed that the transformer can only be loaded up to 65% of its rated capacity due to the increased temperature rise in its High Voltage winding.

Experiments are also conducted on a prototype three phase transformer when connected to linear as well as non-linear loads. It is observed that the temperature rise is more than the permissible limit when the loads are non-linear. This calls for de-rating of the transformer or to use filters to reduce the effect of harmonics.

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Acknowledgement

The authors would like to acknowledge the help rendered by KSEB officials for the collection of failure data of distribution transformers from TMR Division, Thirumala and Sri. Manoj Kumar, AGEIS Power Engineers, Technopark for data collection from the Distribution Transformer installed in NILA building, Technopark.

Drainage Power Recovery From Distribution Transformers

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Abstract

Distribution transformers play a major role in power system by stepping down the primary distribution high tension (HT) voltage to the voltage level required for the low tension (LT) customer. Modern distribution transformers are usually energy efficient when supplying linear loads. However, the increased usage of harmonic producing non-linear loads now-a-days has increased the transformer losses considerably. Moreover the very large number of transformers in distribution systems, supplying power to domestic, commercial, rural and industrial sites cause the total transformer losses to be significantly high.

This paper discusses a modified transformer configuration for recovering the power which is normally wasted in the delta winding of the distribution transformer. The experimental studies conducted on a prototype model shows that the modified distribution transformer helps in not only improving the transformer efficiency but also reduces harmonic distortions and improves system power factor.

1. Introduction

In earlier times the loads used in the distribution system were mostly linear in nature and hence harmonic losses were not a major issue. But now the proliferation of non-linear loads in domestic as well as commercial facilities results in the excessive injection of harmonic components to the utility power system. Triplen harmonics injected by the non-linear loads circulate in the primary delta windings of the conventional delta-star distribution transformers. This leads to increased power loss, temperature rise and subsequent de-rating and reduction in the life of transformers. The power which is usually wasted due to the circulation of triplen harmonics in the primary delta winding of the distribution transformer is termed here as ***drainage power***. This paper discusses a novel transformer configuration for recovering and utilizing the drainage power from distribution transformers and compares the performance of the modified configuration with star-star, delta-star and star-star-delta configurations.

2. Modified distribution transformer configuration

The conventional distribution transformers are of delta-star configuration providing three phase, four wire ac distribution as shown in Fig.1. In such a case, the triplen harmonic currents caused due to non-linear loads get circulated in the primary delta winding resulting in wastage of power (drainage power).

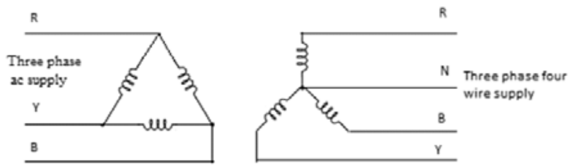


Fig. 1 Conventional ac distribution

In the modified configuration, a three winding transformer as shown in Fig.2 is suggested for power distribution. Both primary and secondary windings of the transformer are star connected. The star connected secondary is providing a three phase, four wire supply as in the conventional system

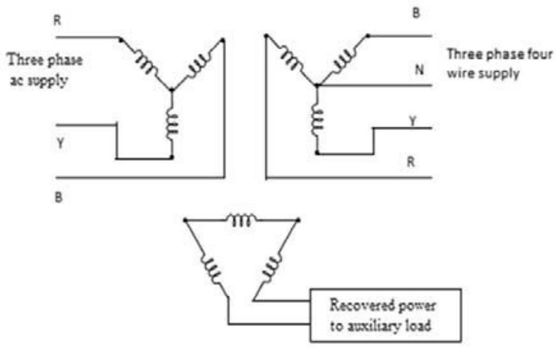


Fig. 2 Modified transformer for ac distribution

The third winding, called the tertiary winding of the transformer is connected in delta providing a path for circulating triplen currents. However, instead of firmly closing together the zero-potential terminals of delta winding, these are used to power auxiliary loads. This ensures that the auxiliary load is powered only by the harmonic power (which would have been otherwise wasted as heat in transformer core and windings, i.e., drainage power) and not by the fundamental frequency power. This modified configuration of distribution transformer is called star-star-delta_utilized (YYD_utilized) configuration.

The triplen harmonics circulating in the tertiary delta will depend on the non-linear loads connected to transformer secondary. Depending on the level of harmonics, the output from the opened delta terminals would be variable voltage, variable frequency supply. This could be directly used for lighting the nearby localities of the transformer with LED lamps or rectified and used for purposes like charging of batteries or power-conditioned and fed back to grid as power quality ac. This scheme of power recovery is shown in Fig. 3.

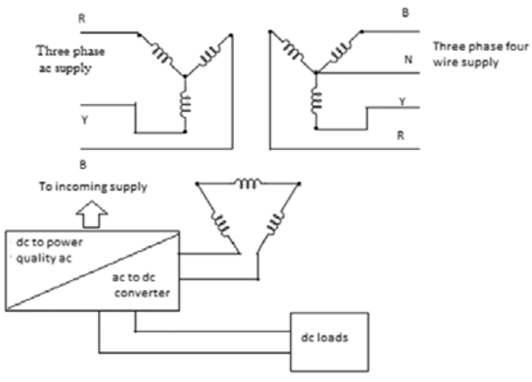


Fig. 3 Proposed drainage power recovery scheme

3. Experimental studies

Experimental studies are conducted on a three kVA prototype model of the YYD_utilized distribution transformer. A turn's ratio of 1:1:1 is selected for experimental convenience. The overall view of the experimental setup is shown in Fig. 2. The primary and secondary windings of the transformer are star connected. Across the zero potential terminals of the tertiary winding, lamp loads (two 40 W, 120 V bulbs in parallel) are connected. When the transformer secondary is connected to rectifier load, which is a non-linear load, the lamps are lighted. But when the transformer secondary is connected to resistive load, which is a linear load, it is observed that the lamps are not glowing. This is because for resistive load there are no triplen harmonics in the delta winding which could power the lamp and since the lamps are connected across the zero potential terminals of tertiary delta, there cannot be any fundamental frequency power across the terminals. When the transformer is connected to rectifier load the lamps are lighted by the recovered harmonic power from the tertiary delta winding which would have been otherwise wasted as circulating current in the transformer core and windings (drainage power).

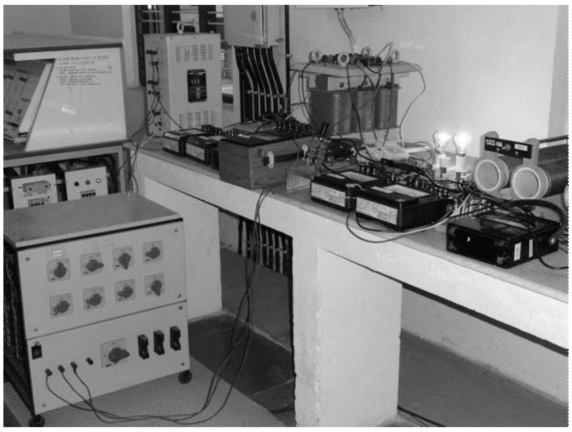


Fig. 4 Experimental setup showing lighting of lamp using recovered power from the delta winding

Table-1 shows the harmonic components present in the circulating current of tertiary delta winding which is powering the lamp load. From the table it can be observed that the magnitude of fundamental frequency component (order of harmonics = 1) is only 0.02A which is quite negligible.

TABLE-1

HARMONIC COMPONENTS IN THE TERTIARY DELTA WINDING

Order of harmonics	Magnitude (A)	Order of harmonics	Magnitude (A)
1	**0.02**	**9**	**0.12**
2	0.00	10	0.01
3	**0.56**	11	0.02
4	0.02	12	0.00
5	0.02	13	0.02
6	0.01	14	0.00
7	0.01	15	0.05
8	0.01	16	0.00

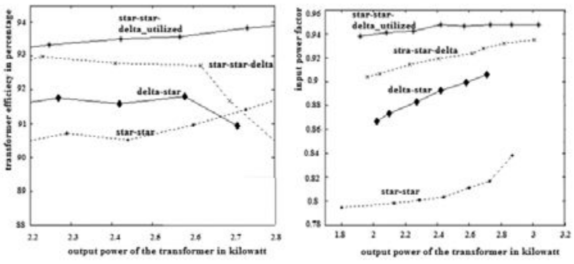
The major harmonic components present in the circulating current are found to be triplen harmonics i.e., third harmonic component of 0.56 A and ninth harmonic component of 0.12A. This is the current which powers the lamp. This proves that the power recovered across the zero potential terminals of the tertiary delta for balanced secondary loading is harmonic power and not the fundamental frequency power.

In the second stage of experimentation the zero potential terminals of tertiary delta are connected to rectifier and the rectified output is connected to resistive load. Each phase of the star connected secondary is connected to a non-linear load and balanced loading is ensured throughout the experimentation. For different balanced loadings of the non-linear load connected to transformer secondary, the effects of the modified transformer configuration (star-star-delta_utilized) on efficiency, power factor and harmonic distortions are studied. For proving the effectiveness of star-star-delta_utilized transformer, experiments were also performed on conventional transformer connections like star-star, star-star-delta and delta–star configurations.

4. Results and analysis

Fig. 5 (a) shows the efficiency characteristics for different transformer connections. The efficiency of the transformer with star-star-delta_utilized configuration is found to be the highest (93.3% - 94%) compared to other connections. This is obvious since with the proposed configuration, the power which is usually wasted in the delta winding is recovered and utilized. Efficiency is found to be the least for star-star transformer (90.5% - 91.6%). It is also interesting to note that the efficiency curve in the case of the proposed system is relatively flat.

Fig. 5(b) shows the variation of input power factor for different winding configurations. Even though the secondary non-linear load of the transformer remains the same, the input power factor varies depending on the configurations. As expected the power factor is highest for star-star-delta_utilized configuration compared to other connections. It is found that the power factor profile remains flat for star-star-delta_utilized transformer and is maintained at 0.94-0.95 for variations in the transformer output power.



(a) Efficiency Characteristics (b) power factor characteristics

Fig. 5 Transformer efficiency and input power factor for different transformer configurations

Fig.6. shows the percentage total harmonic distortion (THD) in the input line current for various transformer configurations. The distortions are least for star-star-delta_utilized configuration and are highest for star-star configuration. Reduced current distortions of star-star-delta_utilized transformer will result in better sinusoidal approximation of the utility line currents.

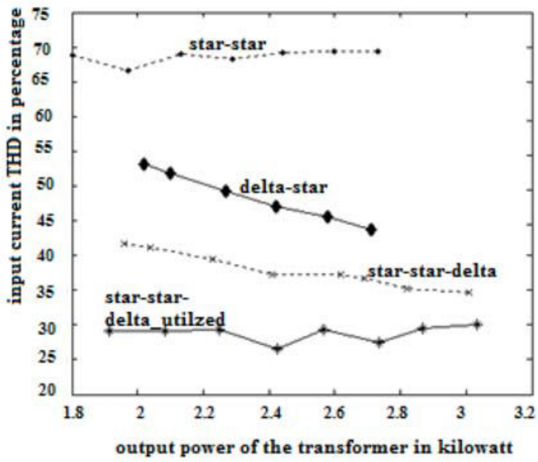


Fig. 6 Comparison of input current THD for different configurations

Thus there is significant reduction in harmonic distortions, considerable improvement in power factor and transformer efficiency with YYD_utilized transformer configuration.

5. CONCLUSIONS

A modified distribution transformer for recovering and utilizing drainage power is discussed in this paper. Modifying the existing delta-star distribution transformer to star-star-delta_utilized configuration requires an additional tertiary winding. But this additional winding needs to have only a fractional capacity of main windings and hence the increase in cost of transformer is only marginal. In the case of a conventional distribution transformer supplying modern non-linear loads, the pay-back period can be a few months. The scheme could be more cost effective if the recovered power can be directly utilized (without any conversion) for purposes like street lighting of nearby localities of the transformer.

The results of the experiments conducted on a three kVA transformer shows that when the tertiary delta harmonic power is recovered and utilized the transformer efficiency increases. The star-star-delta_loaded configuration also results in better power factor and reduced distortions (current THD) in the primary supply compared to other configurations. The implementation of this scheme will lead to better distribution system which will give better energy efficiency, improved power factor for the power network. The scheme can reduce harmonic losses in the power grid, can improve the efficiency and extend the life of distribution transformers.

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Biographies

P.S. Chandramohanan Nair received his bachelors and masters degrees in Electrical Engineering from College of Engineering, Trivandrum, India in 1975 and 1978 respectively. He obtained his Ph.D. degree from Centre for Energy Studies I.I.T Delhi in 1992. Currently he is professor and Chairman of Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham (Amrita University), Kollam, Kerala, India.

Earlier he worked with Govt. Engineering Colleges in Kerala in various capacities as Lecturer to Principal. He also worked on deputation as the first Head of R&D wing of Energy Management Centre, Govt. of Kerala and as Director, Agency for Non-conventional Energy and Rural Technology (ANERT), Govt. of Kerala. His fields of interests are power system dynamics, energy conservation and management.

Preetha P. K. received her bachelors and masters degrees in Electrical & Electronics Engineering from College of Engineering, Trivandrum, Kerala, India in 1995 and 1997 respectively. Currently she is Assistant Professor of Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham (Amrita University), Kollam, Kerala, India and also working towards her Ph.D. degree. Her research interests include power quality and power system control.

[Dr. P.S.Chandramohanan Nair was Awarded Govt. of Kerala Energy Conservation Award 2011 in the Research & Innovations category based on this work.]

National Energy Conservation Day - 14th of December.

National energy conservation day is celebrated every year by the people all over the India on 14th of December. The Energy Conservation Act in India was executed by the Bureau of Energy Efficiency (BEE) in the year 2001. The Bureau of Energy Efficiency is a constitutional body which comes under Government of India and helps in the development of policies and strategies in order to reduce the energy use. The Energy Conservation Act in India act aims to employ the professional, qualified and energetic managers as well as auditors who are with expertise in managing the energy, projects, policy analysis, finance or implementing the energy efficiency projects.

COOL ROOFS

AN ENERGY SAVING TECHNOLOGY

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Abstract- **Heat flows from warm place to cold place. When too much heat gain or loss occurs, the air conditioning system operates to keep the space comfortable. Cool roofs lessen the flow of heat from the roof into the buildings, reducing the need for space cooling energy. Cool roof surface reflects sunlight and efficiently cools itself by emitting thermal radiation. It combines building energy stimulations, local energy prices, local electricity emission factors and local estimates of building density to characterize local, state and national average cooling energy savings, heating energy penalties, energy cost savings, emission reductions per unit roof area. The commonly used cool roof coatings are asphalt cap-sheet, gravel, various single ply- materials, membranes and roofing tiles. Cool roof does not imply that the roof is essentially white in colour. Cool roofs are designed by giving due considerations to the surroundings, slope and weight of the roof, moisture control, energy efficiency of the buildings and the presence of roof top solar equipments. The benefits from cool roofs include energy savings (10-30%), HVAC equipment downsizing, extended roof life, reduced effects of urban heat island, lower air pollution, reduced green house emission etc. Cool roof coatings protect roof surfaces from UV light and chemical damage, offers water protection and also some restoration features.**

Keywords – solar reflectance, solar absorptance, thermal emittance, solar reflective index, thermal resistance

I. INTRODUCTION

According to the Intergovernmental Panel on Climate Change, the Earth's average temperature is on a track to increase by between 2 and 7 degrees Celsius this century. Cities are often significantly warmer than the surrounding landscapes owing to the lack of vegetation. Compared to the surrounding landscape, urban areas are found to release more heat from human activities like air conditioning, vehicles, industry etc. Addressing this heating effect (called the urban heat island effect), has gained prominence since the world is urbanizing rapidly with its 80 percent population anticipated to occupy the urban areas within the next 50 years. The entire building industry has now turned its focus towards green movement, and the roofing segment is perhaps the most strongly focused area. These dark surfaces absorb over 80 percent of sunlight that comes in contact with them, converting the solar energy into heat; thus our built environment becomes responsible for maximising the warming effects of climate change. Builders are enthusiastic about upgrading their buildings with features that are sustainable, durable and also beautiful. Now a day they are basing their product decisions on long term values rather than short term price.

II. COOL ROOFS: DEFINITON AND TERMINOLOGY

A. Definition

Cool Roofs are roof products made from highly reflective and emissive materials that can significantly reduce the temperature of the roof and subsequently reduce the transfer of heat through the roof. To understand how Cool Roof works, it is essential to understand the scientific properties of Cool Roofs.

B. Terminology

a) Solar Reflectance (SR or albedo) is the fraction of sunlight that is reflected from a surface. A value of 0 indicates that the surface absorbs all solar radiation, and a value of 1 represents total reflectivity. SR typically ranges from about 0.04 (or 4 percent) for charcoal to 0.9 (or 90 percent) for fresh snow. High solar reflectance is the most important property of a cool surface. Most dark roof materials reflect 5 to 20% of incoming sunlight, while light-coloured roof materials typically reflect 55 to 90%.

b) *Solar Absorptance (SA)* is the fraction of sunlight (0 to 1, 0 percent to 100 percent) that is absorbed by a surface. Surfaces with high solar absorptance tend to get hot in the sun. If the surface is opaque, solar absorptance equals 1 minus solar reflectance.

c) *Thermal Emittance* describes how efficiently a surface cools itself by emitting thermal radiation. It is measured on a scale of 0 to 1, where a value of 1 indicates a perfectly efficient emitter. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all non-metallic surfaces have high thermal emittance, usually in the range of 0.80 to 0.95. Uncoated metal, bare, shiny metal surfaces, like aluminium foil, have low thermal emittance, which helps them stay warm. A bare metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation.

d) *Solar Reflective Index (SRI)* is another metric for comparing the "coolness" of roof surfaces. It is a coolness indicator that compares the surface temperature of a roof on a sunny summer afternoon to those of a clean black roof (SRI=0) and a clean white roof (SRI=100). SRI is computed from solar reflectance and thermal emittance, and can be less than 0 for an exceptionally hot surface (e.g., a solar collector) or greater than 100 for an exceptionally cool material (e.g., a very bright white roof). The higher the SRI, the cooler the roof will be in the sun. Dark roofs usually have an SRI less than 20.

e) *Thermal Resistance (R-value)* is a measure of a material or system's ability to prevent heat from flowing through it. The thermal resistance of a roof can be improved by adding insulation, radiant barrier, or both.

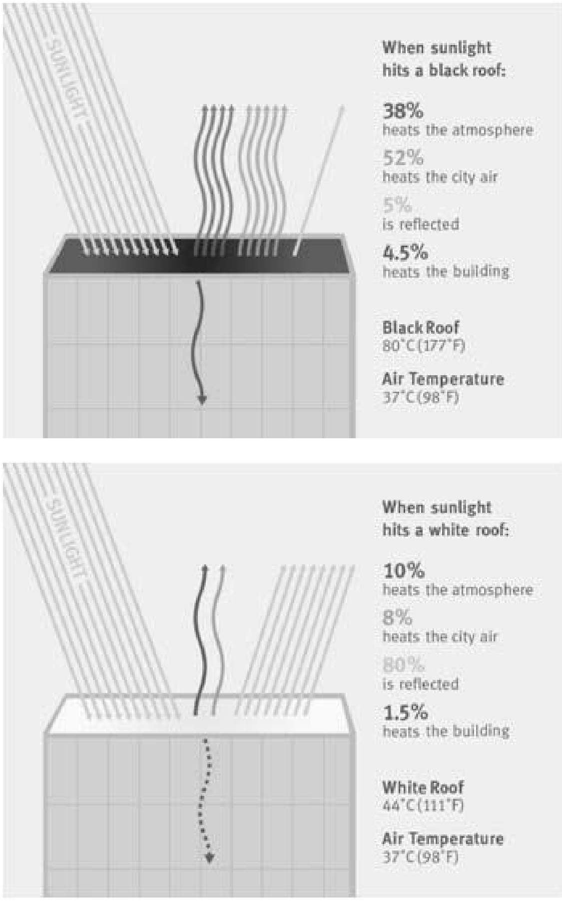

Fig.1. Fate of sunlight incident on black roof and white roof (working of cool roofs)

III. TYPES OF COOL ROOF APPLICATION

A. Low sloped Cool Roof

A low-sloped roof is essentially flat, with only enough incline to provide drainage. It is usually defined as having not more than 2 inches vertical rise over 12 inches of horizontal run or a 2:12 pitched. These roofs are found on the majority of commercial, industrial, warehouses, office, retail and multifamily buildings as well as some single-family homes. . Common steep-slope roofing materials include:

- Ethylene Propylene Diene Monomer (EPDM) is a synthetic rubber material manufactured as a vulcanized (cured) membrane that is formulated with extensive flexibility for use as membrane sheet roofing.

EPDM membranes range in thickness of 1mm to 2mm. EPDM membranes exhibit good resistance to ozone, UV rays, weathering, abrasions and has good low temperature flexibility.

• Polyvinyl Chloride (PVC) polymers are thermoplastic membranes, produced through the polymerization of vinyl chloride monomers. PVC is most commonly used cool single-ply which has seams that are typically heat welded to give a very secure seal. PVCs have good flame resistance, but if burned they tend to smoke with toxic hydrogen chloride gas. Plasticizers are added for flexibility; when they are leached out over the years, the roof material becomes brittle and discoloured.

• Thermoplastic Poly Olefin (TPO) is another thermoplastic type of cool single-ply roofing material. TPO roof membranes are compounded from a blend of polypropylene and ethylene-propylene rubber polymers. TPO membranes exhibit positive physical properties, such as heat aging, cold temperature flexibility, puncture resistance and tear strength. In this material plasticizer is not used. They tend to be more dirt resistant than PVC but the material can be overheated making heat welding tricky. Some additives are added to make it fire resistant.

• Chlorosulphonated Poly Ethylene (CSPE) (commercially known as Hypalon) is the most expensive among all cool single-ply roofing materials. It provides good weather resistances, fire resistance, and durability. As the material is thermoplastic when installed, heat welds are applied to the seams; the roofing cures to thermo set within days.

• Cool Roof Coatings

In re-roofing projects, cool roof coatings are commonly used. Mostly bright white paint like materials is applied to traditional roofs or metallic surfaces. The coating extends the life of the underlying roof materials and greatly increases the solar reflectance.

i. *Cementitious coatings* use cement or ceramic particles to enhance solar reflectance. They can be rolled, sprayed or brushed on the rooftop. If they are properly selected and installed, they perform well. However, they can brittle and crack or peel from surfaces over time.

ii. *Thermoplastic coatings* have a hard surface and are UV and dirt resistant. The clear coat finish increases durability and extends the life of the coating.

iii. *Elastomeric coatings* are also available, with various polymers used for different types of substrates.

B. Steep-sloped Cool Roof

Steep-sloped roofs have an inclination greater than a 2-inch rise over 12-inch run. These roofs are found most often on residences and retail commercial buildings and are generally visible from the street. Common steep-slope roofing materials include:

• Roof Shingles and Tiles are roof coverings normally flat rectangular shapes that are laid in rows without the side edges overlapping. Shingles have been made of various materials such as wood, slate, asbestos-cement, bitumen-soaked paper covered with aggregate (asphalt shingle) or ceramic. Tiles used are made of clay, natural stone, metal or concrete.

• Metal Roofs are roofing systems using metal sheets or tiles as the waterproofing layer, pre-coated so they lend themselves well to Cool Roofs.

• Built-Up Roofing Systems (BUR's) consist of a base sheet, fabric reinforcement layers, and a protective surface layer that is traditionally dark. The surface layer can be made in a few different ways, and each has cool options. One way involves embedding mineral aggregate (gravel) in a flood coat of asphalt. By substituting reflective marble chips or gray slag for dark gravel you can make the roof cool. A second way built-up roofs are finished is with a mineral surfaced sheet. These can be made cool with reflective mineral granules or with a factory-applied coating. Another surface option involves coating the roof with a dark asphaltic emulsion. This type can be made cool by applying a cool coating directly on top of the dark emulsion

• Modified Bitumen Sheet Membranes are composed of one or more layers of plastic or rubber material with reinforcing fabrics, and are surfaced with mineral granules or with a smooth finish. A modified bitumen sheet can also be used to surface a built-up roof, and this is called a "hybrid" roof. Modified bitumen surfaces can be pre- coated at the factory to make them cool.

• *Cool Colours*

White is the coolest colour, but there are cool versions of a wide variety of colours. Highly reflective roofs can come in popular colours such as red, green and gray. For all types of steep-sloped and low-sloped roofs, cool coloured materials are available. These materials include asphalt shingles, metal, clay tiles, and concrete tiles. Highly reflective coloured roofs have an initial solar reflectance ranging from 0.30 to 0.55, compared with around 0.10 for conventional dark steep-sloped roofs.Many roofs materials in any colour can be treated with a reflective coating, giving them a higher solar reflectance than the standard version of that material.

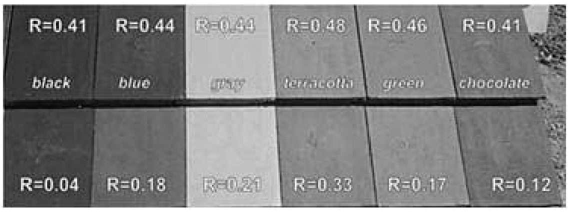

Fig. 2. Comparison between cool roofing and ordinary roofing materials

Iv. DESIGN CONSIDERATIONS

A. Suitability of Cool Roofs

Cool roofing can suits well in the following cases:

- The building is in a climate with hot and sunny weather during at least a part of the year.
- Significant cooling energy is used.
- The duct system is in attic or plenum space.
- The roof accounts for much of the building's envelope.
- There are problems in maintaining indoor comfort in the summer.
- The roof material tends to crack and age prematurely from sun damage

B. Choosing the Right Cool Roof Option

The cool roof option available depends on the building and roof type. For commercial buildings flat roofs (low-sloped roofs) are preferred while for residential buildings steep-sloped roofs are preferred. The desirability of cool roofs depends on the latitude, altitude, annual heating and cooling loads, peak energy demands, and sun blockage by trees, buildings, and hills for the particular building.

C. Testing Standards for Evaluating Coolness of Roofing Materials

a) Solar reflectance:

- ASTM E 903
- ASTM C 1549
- ASTM E 1918
- CRRC TEST METHOD (portable solar reflectometer)
- ASTM E 1980

b) Thermal emittance

- ASTM E 408-71
- ASTM C 1371

D. Resources

a) Policy and code bodies

- *ECBC 2007*

"Roofs with slope less than 200shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75"

TABLE I SRI RECOMMENDATIONS FOR THE COOL ROOF TYPES

Roof Type	Slope	SRI
Low- slope roofs	2:12 (15%)	78
Steep-sloped roofs	>2:12(15%)	29

- ***GRIHA** (The Energy And Research Institute)*

- More than 50% of the paved area to have previous paving/ open-grid pavement/grass paver or
- A minimum of the 50 % of the paved area(including parking) to have shading by vegetated roof/pergola with planters or
- A minimum 50% of the paved area to be topped with finish having solar reflectance of 0.5 or higher

a) Savings calculators

The roof savings calculator is a simple and free online tool that allows the users to calculate annual energy savings associated with choosing cool roof instead of a dark roof. The Cool Roof Calculator helps in comparing two identical building models that differ by the roof external finish. The users can input the parameters of the building either in the simple calculator or the detail calculator, based on which the energy savings and payback, or the comfort shall be calculated. The Calculator can simulate weather conditions for all major cities in India.

Using the savings calculator, for an office building of 130 m^2 in Trivandrum city, the annual savings achieved due to cool roof (Reflectivity 0.7, Emmissivity 0.9) as compared to normal roof (Reflectivity 0.3, Emissivity 0.9) is 7,606 kWh , which results in an annual savings of Rs. 15,211. In 10 years duration the extra cost of material for cool roof is Rs. 300 per sq. m and the electricity savings are 58.51 kWh/m^2/Year (i.e. Rs. 117.02). The payback period for the extra cost incurred in cool roofing is estimated as 2.56 years.

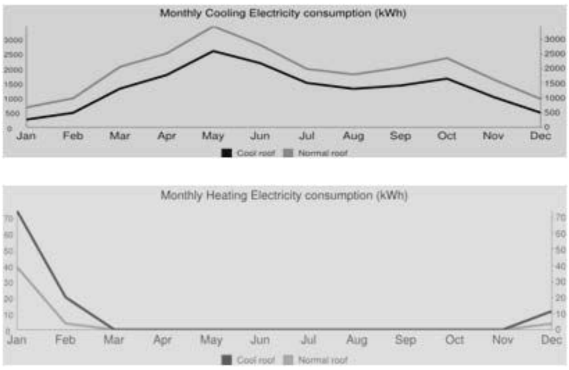

Fig.3. Output obtained from savings calculator

E. Cool Roof Economics

The energy and cost savings that can be achieved by using cool roofing technologies depend on many factors, such as climate and building characteristics. Three aspects of cool roofing technologies also affect their cost-effectiveness:

- The aged solar reflectance and thermal emittance of the roof (since many roofs become less reflective over time, energy savings should be based on long-term values of solar reflectance and thermal emittance).
- The incremental initial cost of the cool roof
- The incremental cost of keeping a cool roof clean and reflective

Roofs costs should be evaluated using a life-cycle approach that accounts for the upfront costs as well as the ongoing savings and expenses incurred throughout the roof's service life.

Life cycle analysis:

- If the roofs need to be installed freshly or replaced cool roof options cost similar to that of non-cool alternatives.
- For a roof that is in good condition, cool roof installations results in higher cost involvement.

F. Maintenance

The cost of maintaining a cool roof is similar to non-cool roofs. Soiling of roof reduces solar reflectance which necessitates annual cleaning.

G. Comparisons between Different Roofing Options.

TABLE II COMPARISON BETWEEN DIFFERENT ROOFING OPTIONS

Criteria	**Cool Roofs**	**Green Roofs**	**Solar PV**	**Insulation**
Storm water management		✓		
Clean energy generation			✓	
Energy savings	✓		✓	✓
Building cooling	✓	✓		✓
City cooling	✓	✓		
Maintenance	✓			✓
Compatibility with other roofing strategies	✓	✓	✓	✓

V. BENEFITS

- Reducing utility bills associated with air conditioning
- Increasing occupant comfort and avoid installing an air conditioner where there isn't already one
- Decreasing the size and prolong the life of air conditioning system
- Lowering roof maintenance costs and extend roof life, avoiding reroofing costs and reducing solid waste

- Assist in meeting building codes
- Mitigate community's Urban Heat Island Effect
- By reducing the air temperature, cool roofs decrease the rate of smog formation
- Maintain aesthetics with a roof that performs and looks good
- Cool roofs directly reduce green house gas emissions by conserving electricity for air conditioning therefore emitting less CO2 from power plants.

VI. PRECAUTIONS AND CONSIDERATIONS

Cool roofs must be considered in context of their surroundings. A bright reflective roof could reflect light and heat into the higher windows of taller neighbouring buildings. In sunny conditions, this could result in glare and unwanted heat. This excess heat could increase air conditioning energy use.

Designing a cool roof that can withstand and control moisture is essential since uncontrolled moisture is essential could cause damage to the roof or to the building.

In case of highly energy efficient buildings, dark roofs on well-insulated buildings can become very hot, so cool roofs helps to achieve the environmental benefits associated with lower roof temperatures. Keeping a roof cool may also extend its life time.

Cool roofing materials should not be misunderstood as white paints. The major difference between paints and coatings are that paints are cosmetic in nature and significantly thinner applications than coatings.

On permanent shaded portions of the roof, the roof's solar reflectance does not affect air conditioning demand. This includes regions that are permanently shaded by solar panels.

VII. LIMITATIONS

Snow cover on roofs can reduce the difference in solar reflectivity between cool and non-cool roofs.

The amount of useful energy reflected by the roof in the winter tends to be less than the unwanted energy reflected in summer.

Net cost savings in energy consumption will be lesser in areas with high heating demands.

XIII. CONCLUSION

The introduction of this system significantly reduces the energy consumption which is one of the major technology challenges in the present scenario. The benefits of installing cool roofs on buildings could be evaluated. Both capital cost as well as maintenance costs incurred for the technique is identified to be satisfactory. This technique can help buildings to meet passive housing standards for LEED Certification.

ACKNOWLEDGEMENT

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ENGINEERS' DAY

September 15

September 15 is celebrated every year in India as Engineer’s Day to commemorate the birthday of the legendary engineer Sir M. Visvesvaraya (1860-1962).

The KSEBEA observes the Engineers day every year. This is celebrated throughout the state through all our units.

Er. Mokshagundam Vishveshwariah, (popularly known as **Sir MV**)was a notable Indian engineer, scholar, statesman and the Diwan of Mysore during 1912 to 1918. He was a recipient of the Indian Republic’s highest honour, the Bharat Ratna, in 1955. He was knighted as a Commander of the British Indian Empire by King George V for his myriad contributions to the public good. Every year, 15 September is celebrated as Engineer’s Day in India in his memory. He is held in high regard as a pre-eminent engineer of India. He was the chief designer of the flood protection system for the city of Hyderabad, now capital city of Andhra Pradesh, as well as the chief engineer responsible for the construction of the Krishna Raja **Sagara** dam in Mysore. He was born in Muddenahalli in Karnataka state.

Space Based Solar Power: Our future hope

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Abstract- **Solar Power Satellite (SPS) is an energy system which collects solar energy in space and transmits it to the ground. It has been believed as a promising infrastructure to resolve global environmental and energy problems for human beings. This is an emerging technology which is under a heavy research phase. Here geosynchronous satellites are used for collecting sunlight, utilizing it to produce solar power and transmitting the generated power back to Earth using Wireless power transmission (WPT), safely, efficiently and reliably. The main advantage of placing solar cells in space is the 24 hour availability of sunlight. Also the urgency of finding an alternative energy source due to the depleting energy resources on earth. Here we study the concept of Solar Power Satellites (SPS), investigate the feasibility of implementation, the overall architecture & the underlying components. The results highlight the effectiveness of this system as an environment friendly, low-loss and large-scale method of energy transfer.**

Keywords— Space Based Solar Power (SBSP); Solar Power Satellites (SPS); Tesla, Wireless Power Transfer (WPT); Rectenna.

1. INTRODUCTION

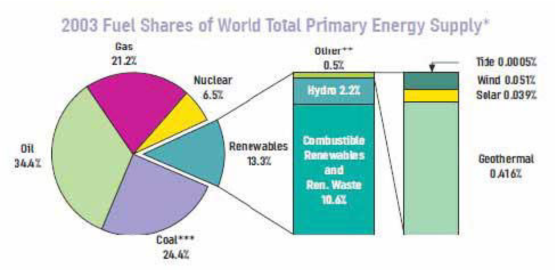
"Energy and environment" is one of the most important global issues to be resolved to sustain our society. 85 % of energy in our life comes from fossil fuels. If we continue to use the fossil fuel resources at the current consumption rate, they will be completely lost within 100-150 years. Furthermore, the huge amount of consumption of fossil fuel Increases CO2 concentrations in the atmosphere, which raises serious environmental concerns. If we continually depend on the fossil fuel, we will experience substantial degradation of life quality within this century. So there is an ever increasing need for the production of power due to the rapid increase of population in the world and increasing per capita power consumption. Since most of the world's energy supply today comes from burning fossil fuels, biogas etc., or from nuclear fission, which have harmful effects on the environment. Also fossil fuels are exhaustible. Even though some inexhaustible and non

polluting energy production methods such as solar energy, tidal energy and geothermal energy are used, at present they can only supply a small portion of the global energy needs. This situation certainly demands for an

alternative energy source for future generations. The advent of solar cells gave an impetus to harnessing the solar power as a renewable energy resource. This is where the prospect of using **Space-based Solar Power** [1][3][5] arises. In outer space there is an uninterrupted availability a huge amount of solar energy in the form of light and heat. 1So the use of satellites to collect the solar energy and beam it back to the earth is being considered. Solar panels can be fitted to the satellites to collect the solar energy and convert is to DC energy. This is not a new concept for satellites, because this method is already in practice to supply the power for the satellites in orbit. What is new is the concept of transmitting the energy back to the earth to produce electricity. This method of producing electric power is possible and it can solve all the world's energy problems.

1.1 Market for power

The growing population and constant industrial developments have exponentially increased the amount of power consumed by the world. The trend according to many scientists will continue for quite some time and the demand for power is only set to increase. By 2050, according to some estimates, 10 billion people will inhabit the globe—more than 85 percent of them in developing countries. The global



energy marketplace is very dynamic. World population is increasing by about 80 million each year [6]. From the below given figure we can understand that the main source of world's energy supply is oil and coal.

Fig 1.1 The share of different sources in the world's energy supply. [7]

The US Department of Energy (DOE) Energy Information Agency (EIA) [17][16]has projected that the world-wide use of energy will approximately double in the next twenty years - and that it will about double again in the twenty years that follow. These projections are founded on the ongoing growth in populations in the developing world and simultaneous growth in the per capita consumption of power in those nations. The development of a nation is related directly to the power that it consumes. The more remote places of the world are being connected to the grid and more countries are undergoing development. Thus the need for power is exploding at a phenomenal rate.

2. SPACE BASED SOLAR POWER

2.1 Solar power

Solar energy is the radiant light and heat from the Sun that has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation along with other resources such as wind power, wave power, hydroelectricity and biomass account for most of the available renewable energy on Earth. Only a minuscule fraction of the available solar energy is used.

Source	Clean	Safe	Reliable	Base-load
Fossil Fuel	No	Yes	Decades remaining	Yes
Nuclear	No	Yes	Fuel limited	Yes
Wind Power	Yes	Yes	Intermittent	No
Ground Solar	Yes	Yes	Intermittent	No
Hydro	Yes	Yes	Drought; Complex	Yes
Bio-fuels	Yes	Yes	LimitedQty-Complex	No
Space Solar	Yes	Yes	Yes	Yes

Table 2.1 Comparison of all available energy source

From the comparison table we can infer that the only source that satisfies all the factors mentioned above is space solar power. **Solar power** provides electrical generation by means of heat engines or photovoltaic cells. Once converted, its uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, daylighting, hot water, thermal energy for cooking, and high temperature process heat for industrial purposes.

2.2 Space based solar power(SBSP)

Space-based solar power is the concept of collecting solar power in space for use on earth. (SBSP would differ from current solar collection methods in that the means used to collect energy would reside on an orbiting satellite instead of on earth's surface). [1][3][4][5]

2.2.1 Benefits of space based solar power

The sun's radiation can be converted into electrical energy even is space using the any of the current methods employed to generate solar power such as photovoltaic cells, but there are certain advantages of collecting solar energy in space using satellites. The sun's energy is almost continuously available to a satellite located in a geosynchronous orbit about the earth (leading promoters of space based solar power schemes to dub it “base load solar power”). A 2007 study by the Pentagon’s National Security Space Office which included representatives from DOE/NREL, DARPA, Boeing and Lockheed-Martin found that a onekilometer- wide band of space in earth orbit receives enough solar energy in just one year (approximately 212 terawatt-years) nearly equal to “the amount of energy contained within all known recoverable conventional oil reserves on Earth today” (approximately 250 TW-yrs).[17][16] .Every 1 km-wide insolation band at GEO receives nearly as much energy per annum as the content of the entire 1.28T BBLs of recoverable oil remaining

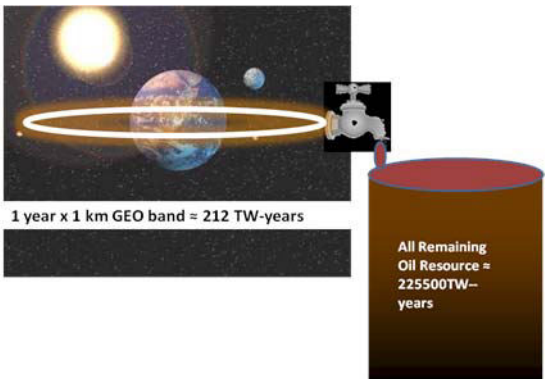


Fig 2.1 Contribution of energy from GEO per year

There are a number of key advantages that make space based solar power an interesting alternative to ground-based solar power:

1. No air & clouds in space, so the collecting surfaces could receive much more intense sunlight, unobstructed by weather
2. A satellite could be illuminated over 99% of the time, and be in earth’s shadow on only 75 min per night at the spring and fall equinoxes
3. High collection rate- the sun is 8-10 times more intense in orbit than on the surface of the Earth ie, is approximately 144% of the maximum attainable on Earth’s surface.
4. Relatively quick redirecting of power directly to areas that it need most
5. Ground-based systems suffer from weather phenomena such as clouds, precipitation, and dust - space based system do not (though the increasing amount of junk in orbit poses a similar hazard)
6. Real estate costs are minimal - the only land that need be acquired is the land for the receiving station.

Transmission line costs are greatly reduced compared to remote generation facilities if the ground station is located near existing transmission lines

2.3 Comparison between SBSP & GBSP

Table 2.2 comparison between SBSP & GBSP

Factors	Space-based solar power	Earth-based solar power
Efficiency	8–10 times more efficient	Less efficient
Effect of external Conditions	not affected	Highly affected
Effect of Earth’s Movement	almost no effect (99%)	generation of energy only during the day
Costs	Only receiving stations no energy storage required	costly real estate set-ups energy storage essentially
Energy loss	no weather, vacuum, no atmosphere=>no loss	atmospheric hindrance =>distorted energy waves

3. THE BASIC CONCEPT OF SPS

The idea of the Solar Power Satellite energy system is placing giant satellites, with wide arrays of solar cells embedded on them, 36000 km above the Earth's surface in the geosynchronous orbit. Every satellite thus will be illuminated by sunlight 24 hrs a day for most of the year [1][2][3][5]. Because of the 23" tilt of the Earth's axis, the satellites pass either above or below the Earth's shadow. The equinox period in both spring and fall is the only time that they will be cast by the shadow. They will be shadowed for less than 1% of the time during the year [1][2]. Dr. Peter Glaser of Arthur D. Little Inc., was the pioneer in introducing the concept of placing huge SPS in the GEO (Geostationary Earth orbit) which can harness the sunlight, turn it into a electromagnetic beam, and transmit this energy to the Earth in form of microwaves. After establishment of this concept in 1968, NASA supported a research project undertaken by Department of Energy of the United States of America, in the years following 1976.

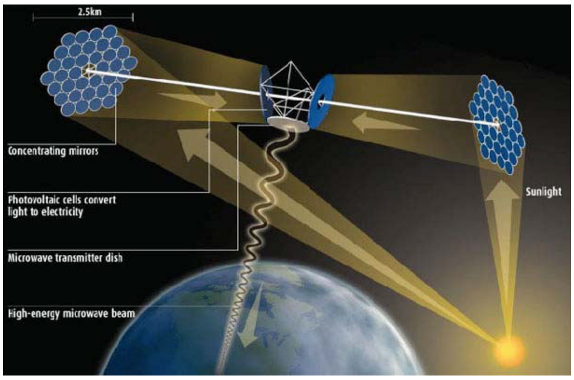
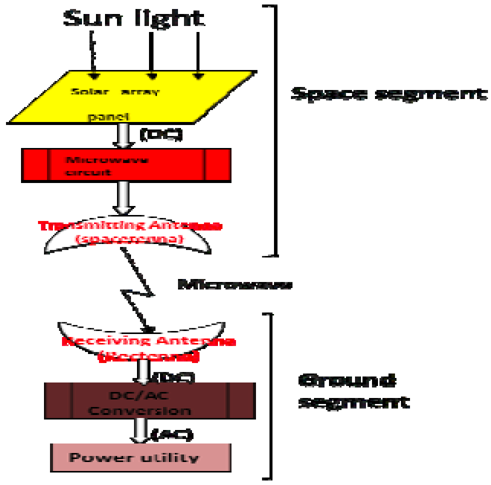


Fig 3.1 The concept of Space based Solar Power Satellite

3.2 Components of an SPS in Orbit:

- The Solar Collector array consists of **photovoltaic** film .
- The **Microwave generating device**.
- The **Transmitting Antenna**
- The **Receiving antenna (Rectenna)**
- **Powergrids**.



3.3 SPS systems

According to Fig 4.1 the entire SPS system consists of two parts, the space segment and ground segment. **Space segment:** The space segment is the satellite part which will be the **space solar power station**.[4] This part is responsible for reception and conversion of solar energy to electrical power and also transmitting the power to earth in the form of microwave energy. The key components of the satellite are solar panels, microwave oscillator, and transmitting antenna. The concept of using solar power in satellites is not new, in fact the satellites in orbit today use solar power to power their on board systems.

3.3.1 Solar energy conversion (solar photons to DC current)

Basic method of converting sunlight to electricity is **photovoltaic conversion** Most analyses of solar power satellites have focused on photovoltaic conversion (commonly known as "solar cells"). Photovoltaic conversion uses semiconductor cells (*e.g.*, silicon or gallium arsenide) to directly convert photons into electrical power via a quantum mechanical mechanism. Photovoltaic cells are not perfect in practice, as material purity and processing issues during production affect performance; each has been progressively improved for some decades. Some new, thin-film approaches are less efficient (about 20% vs. 35% for best in class in each case), but are much less expensive and generally lighter.

Possible designs of solar collectors:

1.Sun tower:

The SunTower[16] is a supertall gravity stabilized structure that uses inflatable circular solar-concentrators, multi-junction solar cells and magnetron segments to transmit the suns energy down to earth. In laymen terms, it is similar in design to a sunflower, with the flower facing the Earth and sending the energy down the stem using microwaves.

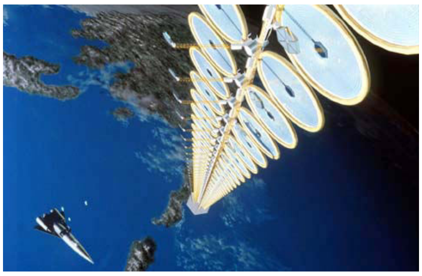


Fig 3.3.1.1 sun tower

2. Solar disc:

It is an axisymmetric, modular space segment that extends in geostationary Earth orbit. It is covered with high-efficiency thin-film solar cells. One SolarDisc along with its ground component could be scaled to produce as much as 10 GW of energy.[16]

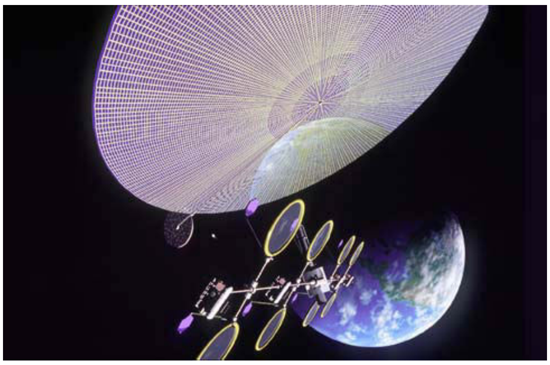


Fig 3.3.1.2 Solar disc

3.3.2 Converting DC to Microwave power

To convert the DC power microwave power for the transmission through antenna to the receiving antenna any microwave oscillator can be used. The various microwave oscillators include the klystrons and magnetron. The magnetron model is most preferred due to high efficiency. [3][1][5]

3.3.2.1 Magnetron Operation

The DC power must be converted to microwave power at the transmitting end of the system by using microwave oven magnetron. The heat of microwave oven is the high voltage system. The nucleus of high voltage system is the magnetron tube. The magnetron is diode type electron tube, which uses the interaction of magnetic and electric field in the complex cavity to produce oscillation of very high peak power. It employs radial electric field, axial magnetic field, anode structure and a cylindrical cathode.[3]

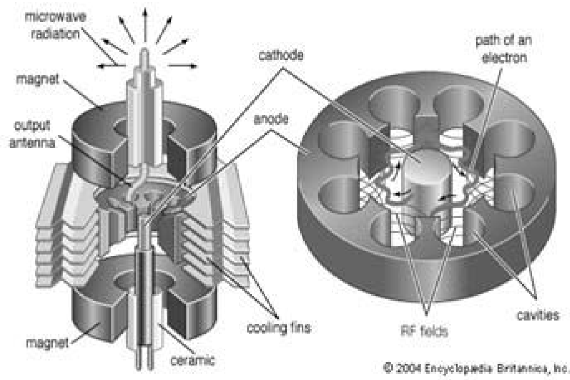


Fig 3.2 Components of Magnetron

The cylindrical cathode is surrounded by an anode with cavities and thus a radial electric field will exist. The magnetic field due to two permanent magnets which are added above end below the tube structure is axial. The upper magnet is North Pole and lower magnet is South Pole. The electron moving through the space tends to build up a magnetic field around itself. The magnetic field on right side is weakened because the self-induced magnetic field has the effect of subtracting from the permanent magnetic field. So the electron trajectory bends in that direction resulting in a circular motion of travel to anode. This process begins with a low voltage being applied to the cathode, which causes it to heat up. The temperature rise causes the emission of more electrons. This cloud of electrons would be repelled away from the negatively charged cathode. The distance and velocity of their travel would increase with the intensity of applied voltage.

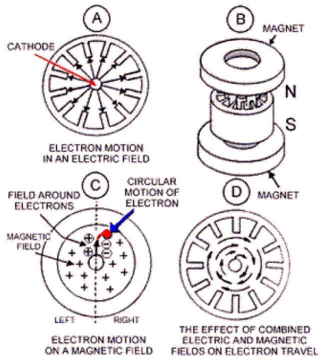


Figure 3 Electron motion in a magnetron tube (Courtesy of Michael S. Wagner)

As the electrons move towards their objective as the figure shows, they encounter the powerful magnetic. The effect of permanent magnet tends to deflect the electrons away from the anode. Due to the combined affect of electric and magnetic field on the electron trajectory they revive to a path at almost right angle to their previous direction resulting in an expanding circular orbit around the cathode, which eventually reaches the anode. The whirling cloud of electrons forms a rotating pattern. Due to the interaction of this rotating space chare wheel with the configuration of the surface of anode, an alternating current of very high frequency is produced in the resonant cavities of the anode. The output is taken from one of these cavities through waveguide. The low cost and readily available magnetron is used in ground.[3]

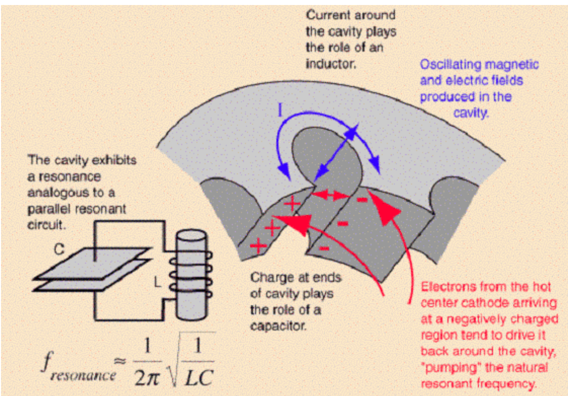


Fig 3.4 Microwave production by Magnetron

3.3.3 Transmitter

The power has to be beamed to the receiving point on earth. The beamed energy has to travel a very large distance (36,000km in GEO) from orbit and through the earth's atmosphere. A very large, high power antenna array has to be used. The phased array antenna model is used to concentrate the beam so that it can reach the target ground station. A **phased array** is a group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.[1][2][5]

3.4 Ground segment

The SPS system will require a large receiving area with a rectenna array and the power network connected to the existing power grids on the ground. Although each rectenna element supplies only a few watts, the total received power is in the gigawatts.

3.4.1 Rectifying antenna (Rectenna)

The word "rectenna" [6][8] is formed from "rectifying circuit" and "antenna." The rectenna receives microwave energy and converts it to DC electricity. The rectenna is a passive element with a rectifying diode, and is operated without any extra power source. It is an antenna comprising a mesh of dipoles(doublet- rabbit ear) and diodes for absorbing microwave energy from a transmitter and converting it by rectification into D.C. power." The rectenna has a low-pass filter between the antenna and the rectifying diode to suppress re-radiation of higher harmonics. Schottky diodes are preferred due to the lowest voltage drop and highest speed. They thus waste the least amount of power for conduction and switching. Large rectennas are formed by an array of numerous similar dipole elements [4][17]. Rectennas are highly efficient at converting microwave energy to electricity. In laboratory environments, efficiencies of over 85% have been observed. It also has an output smoothing filter.

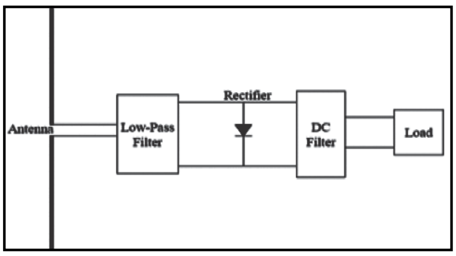


Fig 3.4 Components of Rectenna

- 5000 Mw Receiving Station (Rectenna). This station is about a Mile and Half long.
- The Rectenna Would be Visually Transparent so that it would not interfere with Plant life.

As the figure shown below Rectenna are mainly placed in large farm lands having adequate area such that the entire microwave signals falls on it.

Fig 3.5 Rectenna placed in a farm land

3.5 Typical Efficiency consideration

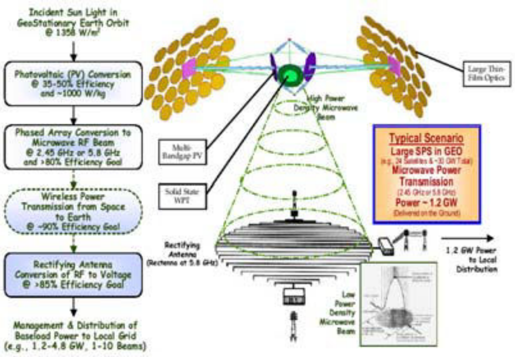


Fig 3.6 Efficiency at each stage of SBSP system

Fig 4.6 shows the typical efficiency at each stage of the space based solar power system. And from this we can infer that most of the stages are having almost high efficiency such as to deliver required amount of power for the distribution of baseload power to local grid.

4. WIRELESS POWER TRANSMISSION

If power is collected in space a mechanism is needed to transfer the power to earth so it can be connected to the power grid and distributed to various locations. But it is not reasonable to connect the space power station to the earth with conducting cables and wire. The wireless transmission of energy [7][9][10] has been contemplated as the most logical solution to cater to the problem of power transmission from space to earth.

4.1 Theoretical Background

It is known that electromagnetic energy also associated with the propagation of the electromagnetic waves. We can use theoretically all electromagnetic waves for a wireless power transmission (WPT). The difference between the WPT and communication systems is only efficiency. The Maxwell's Equations indicate that the electromagnetic field and its power diffuse to all directions. Typical WPT is a point-to-point power transmission. For the WPT, we had better concentrate power to receiver. It was proved that the power transmission efficiency can approach close to 100%.

4.2 Microwave power transmission

Microwave power transmission (MPT)[7][10] is the use of microwaves to transmit power through outer space or the atmosphere without the need for wires. It is a sub-type of the more general wireless energy transfer methods. The reasons for microwave power transmission being the preferred choice for wireless power transmission is because of

- High penetration through atmosphere
- Beamed Power level is well below lethal levels of concentration even for prolonged exposure
- High efficiency up to 85%
- Safety ensured for flying bodies to greater extent.
- Availability of more band width
- The high gain and directivity of the microwaves.

Microwave transmission is usually used in satellite communication. MPT is similar to the microwave transmissions for satellite communication in terms of the antenna array of transmitters and receivers but it has some distinct requirements.

1) For microwave power transmission (MPT), highly efficient energy transmission between the transmitter and the receiver antennas is required. The product of the transmitter and receiver diameters is a key parameter. A huge array is necessary for high efficiency. The diameters are on the order of kilometers and the number of their elements is on the order of billions for the SPS. The efficiency is about 90%.

2) The microwave beam should be correctly directed to the rectenna site. Pointing accuracy 300 m or less from GEO (36,000 km in altitude) is required for a rectenna diameter of a few to several kilometers. This corresponds to 0.0005°.

3) Highly efficient and light weight power transmitters with low harmonics need to be developed. The low weight to power ratio is important for decreasing the launch cost. The microwave devices for the SPS power transmitters are either semiconductor devices or microwave tubes.

4.3 Recommended microwave power transmission

As a result of technical research based on the SPS 2000 conceptual study, wireless power transmission at 2.45 GHz is found to be the most practical method that can be applied for the early stage of space solar power stations. Microwave frequency for SPS has been selected in a range of 1-10 GHz, compromising between antenna size and atmospheric attenuation. If we choose a frequency in the industrial, scientific and medical (ISM) radio bands, 2.45 or 5.8 GHz is the potential candidate. Although various ideas of wireless power transmission have been proposed for future systems, only 2.45 GHz can be recommended to be standardized as a practical standard for the following reasons.

- High efficient transmission
- The frequency in which there is a minimum of atmospheric signal attenuation
- Less Interference with radio communications

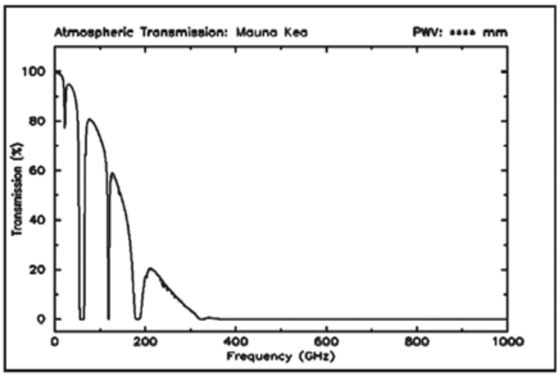


Fig 4.1 Transmission(%) Vs frequency plot

5. ADVANTAGES

1. Unlike oil, gas, ethanol, and coal plants, space solar power does not emit greenhouse gases.[1][3][5]
2. Unlike coal and nuclear plants, space solar power does not compete for or depend upon increasingly scarce fresh water resources.
3. Unlike bio-ethanol or bio-diesel, space solar power does not compete for increasingly valuable farm land or depend on natural-gas-derived fertilizer. Food can continue to be a major export instead of a fuel provider.
4. Unlike nuclear power plants, space solar power will not produce hazardous waste, which needs to be stored and guarded for hundreds of years.
5. Unlike terrestrial solar and wind power plants, space solar power is available 24 hours a day, 7 days a week, in huge quantities. It works regardless of cloud cover, daylight, or wind speed.
6. Rural electrification of remote villages and regions (particularly in developing countries)
7. Mitigate oil dependence[1][11]
8. Prevent resource depletion (and the wars fought over it)
9. Continuous power supply.
10. No need of storage facilities
11. Unlike nuclear power plants, space solar power does not provide easy targets for terrorists.
12. Space solar power will provide true energy independence for the nations that develop it, eliminating a major source of national competition for limited Earth-based energy resources.
13. Space solar power can take advantage of our current and historic investment in aerospace expertise to expand employment opportunities in solving the difficult problems of energy security and climate change.
14. Space solar power can provide a market large enough to develop the low-cost space

transportation system that is required for its deployment. This, in turn, will also bring the resources of the solar system within economic reach. [13],[14]

6. DISADVANTAGES

1. Maintenance of SPS is expensive and challenging.
2. Requires a large reduction in launch and in place costs to compete effectively with ground-based solar.
3. The size of construction for the rectanna is massive. [13][14]
4. Transportation of all the materials from earth to space and installation is highly challenging.

7. CONCLUSION

The growing demand for electric power requires a 50% increase in worldwide generating capacity during the next 25 years. The present prospect is for much greater consumption of coal, nuclear energy and natural gas. Solar energy is the only conceivable alternative, but terrestrial sunlight is too intermittent and diffuse for wholesale power applications. Fortunately, the economies of scale in meeting energy needs overcome the barriers to deployment of solar collectors in space, where sunlight is continuous and intense. Solar power satellites can provide clean, reliable, inexhaustible energy anywhere on Earth.

Based on current research space based solar power should no longer be envisioned as requiring unimaginably large initial investments in fixed infrastructure before the emplacement of productive power plants can begin. Moreover, space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches to meeting increasing terrestrial demands for energy - including requiring considerably less land area than terrestrially-based solar power systems. Though the success of space solar power depends on successful development of key technology, it is certain the result will be worth the effort..

7.1 Future scope

- Perfect market for reusable launch vehicles because they involve launching lots of essentially identical pieces
- It appears to be economically viable in the next 1–3 decades[14][15]
- Low-cost Earth-to-orbit transportation systems appear to be technically feasible during the coming 20–30 years using technologies existing in the laboratory now.[15]

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Performance of Source Separation Alogrithm on Ground Borne Low Level Vibration Signals

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Abstract—**the source separation of ground borne vibration signals is a challenging problem. The separation of a set of signals from a set of observed signal mixtures, without the information about the source signals or the mixing process is known as Blind Source Separation (BSS). BSS depends on the assumption that the source signals do not correlate with each other. The performance of a source separation algorithm FastICA on ground borne low level vibration signals with various sources –sensor distance is studied.**

Keywords- Ground Borne Vibration, Blind Source Separation, Independent Component Analysis, FastICA

I. INTRODUCTION

Vibration is the phenomenon which exists in many ways ranging from heartbeat to earthquakes. This paper considers the problem of the performance of a source separation algorithm on ground borne low level vibration signals. Various parameters like Signal to Interference ratio, Performance Index of separability, Converging time are considered. The choice between various nonlinearity functions to optimize the performance of algorithm on the observed the vibration signals are also studied.

The prediction of vibration propagation through soil is an intricate task, made difficult by the non-homogeneity of the vibration propagation medium (i.e. soil and/or rock). Ground vibration propagates through the soil or rock as waves, so that the amplitude generally decreases with distance from the source. These multiple factors affecting the observed signals make the source separation of ground borne vibration a complex task. The separation has an added complexity of low signal to noise ratio. This can be viewed as a complex version of the classical source separation problem, the "cocktail party problem"[1] where a number of people are talking simultaneously in a room and one is trying to follow one of the discussions. The source separation problem of speech signals is well studied and a blistering topic of research during the last decade. But only few work appeared on the source separation of ground noise. The compressional waves or primary or P –waves, shear waves or secondary or S- waves, and Rayleigh waves or R-waves are the significant ground vibration waves, which propagate through different means and exhibit different behaviors.

In close proximity to the source, compression waves dominate. A general formula for vibration propagation with damping in semi analytical approach can be written as

$$A(r) = A(r_0)e^{-\omega\eta.r/2c} \qquad (1)$$

where *A* is the vibration amplitude, *r* is the source-receiver distance, ù is the frequency in rad·s^{-1}, ç is the soil loss factor (which can be frequency-dependent) and *c* is the compressional or dilatational wave speed[2]. We consider compression waves only for this study as the source sensor distance is small [3].

We studied the performance of FastICA a computationally efficient algorithm for various source –sensor distance. The mixing matrix is based on the source –sensor distance. ICA algorithm does not need source-sensor distance for estimating the Independent Components (IC). It used here for comparing the behavior of the algorithm. The source-sensor distance is the perpendicular distance between the line joining sensors and the line joining the sources. The distance between sensors and distance between different sources are neglected.

A potential application of the method is to track lives buried in ground by capture and examine the noise as slight as shallow breathing, heartbeat, small voice made by the victim, sounds of the movements of limbs etc., which can results in ground borne vibrations [4]. The method can also employ in fault predictions and analysis of rotating machinery, vibration analysis of space craft [5][6][7],vibration analysis of hydro electric station, thermal stations etc.

II. Basic Theory

The separation of a set of signals from a set of observed signal mixtures, without the information about the source signals or the mixing process is known as Blind Source Separation (BSS). BSS depends on the assumption that the source signals do not correlate with each other i.e. the signals are statistically independent or de-correlated [8][9].

It is not easy to measure the distance of the exact vibration sources in many cases and the mixing system is unknown due to the non-homogeneity of earth crust or propagation medium. So we will use the method of BSS. In the case of BSS no information is needed on the source positions or the mixing systems. We use four sensors as shown in the figure.1 for the experiments [10]. The problem is intricate as the signal to noise ratio is low [11]. The mixing and demixing matrix for only one channel is labeled for easy understanding. Co efficient of other channels can be written in similar way.

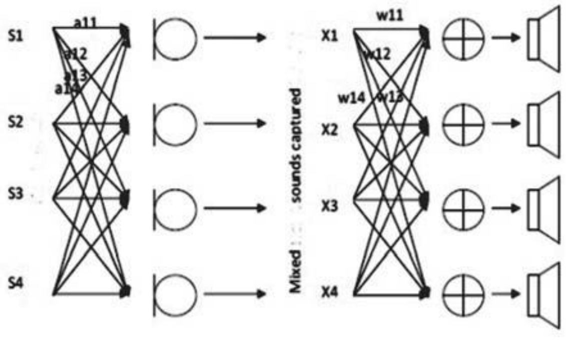

Fig. 1. Schematic of acquisition and source separation of ground borne vibrations

ICA separates multivariate signal into additive subcomponents supposing the mutual statistical independence of the nongaussian source signals [8]. ICA is based on the standard and physically realistic assumption that if different signals are from different physical processes then those signals are statistically independent. The vibrations we consider are produced by different physical activities. The implication of this assumption can be reversed: if statistically independent signals can be extracted from signal mixtures then these extracted signals must be from different physical processes. ICA maximizes non-gaussianity. The problem as depicted in figure. 1 is similar to cocktail party problem [12]. Therefore the sound separation can be stated into (2) to (5); given the source signals s_1, s_2, s_3 and s_4 and the captured signals x_1, x_2, x_3 and x_4 at sensor P1 to P4 as:

$$x_1 = a_{11}s_1 + a_{12}s_2 + a_{13}s_3 + a_{14}s_4 \quad (2)$$

$$x_2 = a_{21}s_1 + a_{22}s_2 + a_{23}s_3 + a_{24}s_4 \quad (3)$$

$$x_3 = a_{31}s_1 + a_{32}s_2 + a_{33}s_3 + a_{34}s_4 \quad (4)$$

$$x_4 = a_{41}s_1 + a_{42}s_2 + a_{43}s_3 + a_{44}s_4 \quad (5)$$

a_{11} to a_{44} are constant coefficients that give the mixing weights. They are assumed to be unknown, since the properties of the physical mixing system are not known. The source signals are also unknown. The original source signals are required to be found from the mixtures x_1 to x_4. This is the blind source separation problem. The equations (2) to (5) can be written as:

$$X = A.S \quad (6)$$

The coefficients a_{ij} are assumed different enough to make the matrix that they form invertible [10]. Thus, there exists a matrix W with coefficients a_{ij}', such that we can separate s_i as:

$$Y = W.X \quad (7)$$

where y is as close to s as possible. If the signals y_1 to y_4 are independent, then they are equal to the original signals s_1 to s_4.

Two methods for measuring nongaussianity are Kurtosis and Negentropy. The FastICA method we used for experiment is based on negentropy. The proceeding sections discuss the method briefly.

The classical measure of nongaussianity is kurtosis or the fourth-order cumulant. The kurtosis of y a random variable, which is centered and has unit variance, can be defined as

$$kurt(y) = E\{y^4\} - 3(E\{y^2\}^2) \tag{8}$$

Since by assumption y is of unit variance, we can write

$$kurt(y) = E\{y^4\} - 3 \tag{9}$$

This shows that kurtosis is simply a normalized version of the fourth moment $E\{y^4\}$. For a Gaussian y the fourth moment equals $3(E\{y^2\}^2)$. Thus kurtosis is zero for a Gaussian random variable. For nongaussian random variables, kurtosis is nonzero [13].

An extension of the basic ICA model is required in this particular case as the SNR is low [14]. We assume that the mixtures instantaneous. The noise is assumed to be additive. Thus, the noisy ICA model can be expressed as

$$X = AS + n \tag{10}$$

where n is the noise vector. More assumptions like the noise is independent from the independent components and the noise is Gaussian is required for the validation of the model.

$$X = A(S+n) \tag{11}$$

The source noise can be modeled with equation (11) where covariance of the noise is diagonal, noisy IC is given by

$$\tilde{S}_i = S_i + n_i \tag{12}$$

and equation (12) can be rewritten as

$$X = A\tilde{S} \tag{13}$$

We see that this is just the basic ICA model, with modified independent components. The assumptions of the basic ICA model are still valid: the components of ,are nongaussian and independent. Thus we can estimate the model in by any method for basic ICA. This gives us a perfectly suitable estimator for the noisy ICA model. This way we can estimate the mixing matrix and the noisy independent components [11].

FAST ICA ALGORITHM

Fast ICA is a computationally efficient algorithm [12]. It uses a fixed point iteration scheme. This is in contrast to ordinary ICA algorithms based on (stochastic) gradient descent methods, where the convergence is linear . It has been found in independent experiments to be 10-100 times faster than conventional gradient descent methods for ICA [15].

The FastICA algorithm is based on a fixed-point iteration scheme which maximizes nongaussianity as a measure of statistical independence. It can be also derived as an approximate Newton iteration. The data is preprocessed by centering and whitening. The FastICA algorithm for one unit is given below. By a “unit” in Fast ICA refer to a computational unit, eventually an artificial neuron, having a weight vector *w* that the neuron is able to update by a learning rule. The FastICA learning rule finds a direction, i.e. a unit vector *w* such that the projection $w^T x$ maximizes nongaussianity. The FastICA is based on a fixed-point iteration scheme for finding a maximum of the nongaussianity of , $w^T x$,

The standard basic form is as follows:

Step 1. *Choose an initial (e.g. random) weight vector w.*

Step 2. *Let* $w^+ = E\{xg(w^T x)\} - E\{g'(w^T x)\}w$

Step 3. *Let* $w = w^+/||w^+||$

Step 4. *If not converged, go back to Step 2.*

Convergence means the old and new values of *w* point in the same direction. It is not necessary that the vector converges to a single point, since *w* and $\bar{\ }w$ define the same direction. This is because the independent components can be defined only up to a multiplicative sign [11]. Pre processing steps centering, PCA and whitening is performed on the signal before application of algorithm

PERFORMANCE MEASSURES

Signal to Interference Ratio

The ratio of the useful signal power to the interference power that determines the performance of the separating system. The SIR is defined as for each pair of signals (y_i, s_j) [16]

$$SIR\_S_{ij} = -10 \log 10 \left(\frac{\|y_i - s_j\|_2^2}{\|s_j\|_2^2} \right)$$

Performance index

The Performance Index (*PI*), defined by [17]:

$$PI = \frac{1}{n(n-1)} \sum_{i=1}^{n} \left\{ \left(\sum_{k=1}^{n} \frac{|w_{tk}|}{max_j |w_{ij}|} - 1 \right) + \left(\sum_{k=1}^{n} \frac{|w_{ki}|}{max_j |w_{ji}|} - 1 \right) \right\} \quad (18)$$

Where *wij* is the $(i,j)^{th}$ element of the global system matrix *W*. The term max*j* |*wij*| is the maximum value along the i^{th} row of *W* and max*j* |*wji*| is the maximum value of the i^{th} column of *W*. When perfect separation is achieved *PI* is zero. In practice this is too optimistic.

III. THE EXPERIMENT

The sources used for our study are four shakers which can produce low level stable vibrations. These sources can be modeled as Omni-directional monopoles [18]. The sensors are high sensitive vibration sensors with 6 V/g at resonance. The signals are amplified using a low noise amplifier and converted to digital signals using a 16 bit ADC. We considered 3 seconds duration clips.

Instantaneous Mixing

To benchmark the performance and validity of the algorithm in the case of vibration signals, we used artificial instantaneous mixtures. The vibration signals from the four shakers v1, v2, v3 and v4 (sources) are recorded using four vibration sensors separately. The signals are artificially mixed using an ill conditioned random matrix . The algorithm FastICA is used to separate the mixed signal [16][19]. Effects of various non-linearity are studied. The highest separation performance is obtained with gauss as non- linearity.

Natural Mixing

The acquisition of the low level ground vibration is challenging as the outdoor field measurements are susceptible to weather condition and various noises hence rugged instruments are needed. The vibration signals from the sources-four shakers v1, v2, v3 and v4 are recorded in the ground at various perpendicular distance from the line joining the sensors.

Both sensors and sources are buried in ground at a depth not greater than 5 cm. The airborne noise is considered negligible. The other types of noise include sensor noise and source noise. The validity of ICA in the noisy environment is discussed earlier in the paper. The source-sensor arrangements and position is given in the figure 2.

The algorithm FastICA used to separate the mixed signal. Effect of various sensor source position and non-linearity on signal separation is studied. The performance index, time taken to converge and the maximum iterations performed for separating the component for various distance and non linearity's are given in the table 1. The Signal to Interference ratio (SIR) for various separated components and the mean SIR is plotted in the figure 3, 4 and 5 for various source-sensor positioning and for three nonlinearity function.

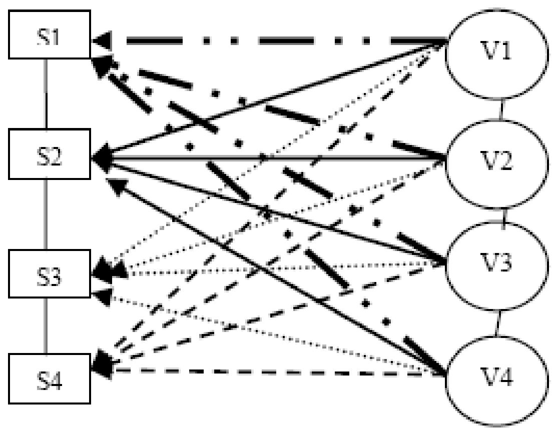

Fig 2: The source-sensor arrangements and position.

Table 1: The performance index, time taken to converge and the maximum iterations performed for separating the component for various distance and non linearity

Source to sensor orthogonal distance (cm)	Non linearity (g)	Time to converge (s)	Performance Index	Max. Number of iterations
0	Cubic	2.34	0.02980	11
	TanH	1.90	0.01538	11
	GAUSS	0.92	0.00274	11
20	Cubic	1.98	0.30712	25
	TanH	2.05	0.32209	33
	GAUSS	2.84	0.21280	169
40	Cubic	2.41	0.34236	12
	TanH	2.03	0.16849	13
	GAUSS	1.03	0.21472	13
60	Cubic	3.79	0.38512	52
	TanH	2.73	0.35192	52
	GAUSS	1.90	0.36606	10
80	Cubic	1.45	0.34828	11
	TanH	1.52	0.34377	19
	GAUSS	1.09	0.39670	27
100	Cubic	367.25	0.22455	196
	TanH	235.09	0.15302	259
	GAUSS	106.32	0.25270	65
120	Cubic	1.37	0.18369	13
	TanH	1.29	0.28131	16
	GAUSS	1.90	0.22423	103

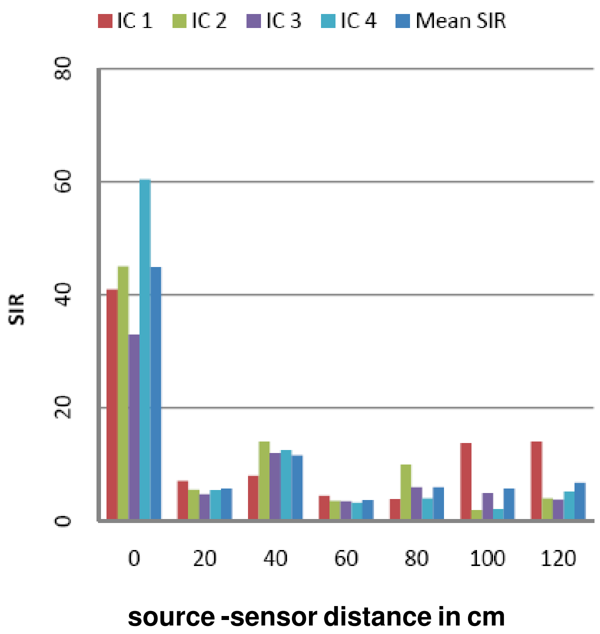

Fig 3: The SIR of separated component with different source sensor distance (Cubic non linearity)

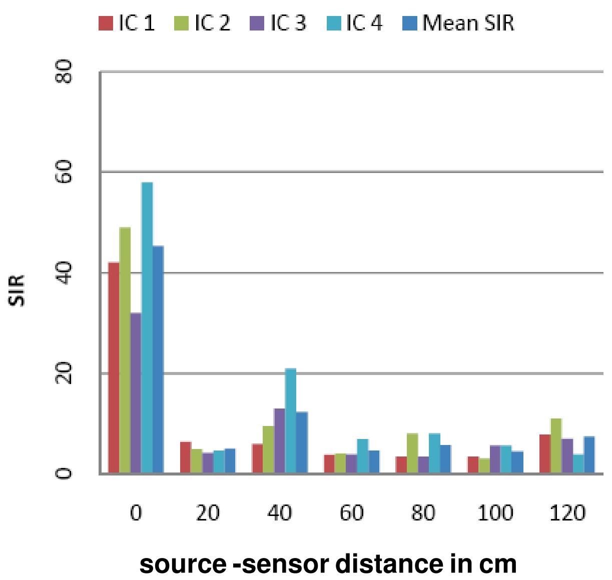

Fig 4: The SIR of separated component with different source sensor distance (Gaussian non linearity)

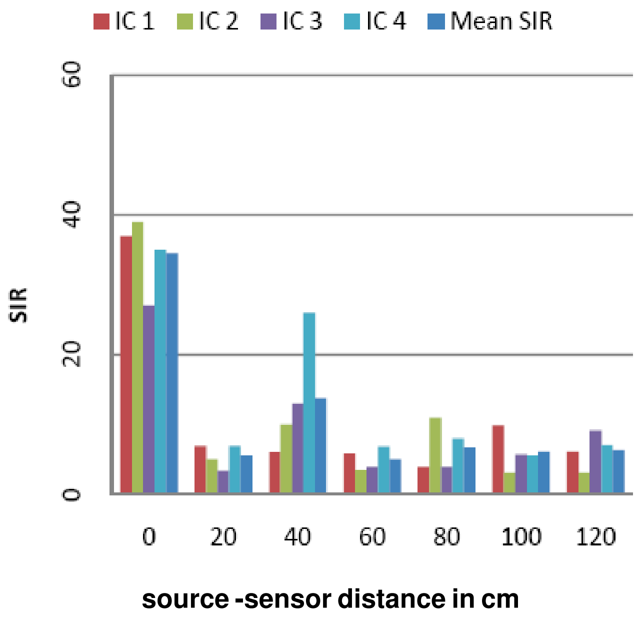

Fig 5: The SIR of separated component with different source sensor distance (Hyper Tangent non linearity)

IV. THE RESULT AND DISCUSSON

We considered the performance of FastICA on artificial as well as real world vibration signal mixtures. In the first case we mixed artificially the different vibrations and performed source separation. In all other cases we captured ground vibration produced by four sources using four sensors directly from the ground for different source-sensor positions. These signals in this case are the mixed signals of the four ground borne vibrations and noise. These signals are amplified and subjected to noise reduction. We considered various non –linearity's for optimization. Theoretically performance index is zero for complete separation. This is very difficult to achieve in practical situation. We achieved a PI=0.00274 in the case of artificial mixing and a PI=0.15302 in the case of natural mixing. The table gives the time taken to separate the mixed signals in various case. The signal to interface ratio of 60.5 and 26 is achieved for the most separated component in the case of artificial mixing and natural mixing respectively. An SIR > 16 shows that separation is achieved. We can see that the performance of the separation is deteriorated in the case of natural mixing and in many cases failed to give an accurate separation. We can infer that the separation performance of the algorithm deteriorates on large SNR of the signals, phase difference of the observed signals, reverberation present in the observed signals etc. The inconsistency of SIR and Performance Index of separability with distance shows that the phase difference is a crucial factor in the performance of the algorithm.

V. CONCLUSION AND FUTURE WORK

In this paper , the performance the FastICA algorithm on ground borne low level real world vibration signal and artificially mixed vibration are studied .The results are tabulated and/ or plotted. The effect of various non linearity on the performance of the algorithm is studied and the results obtained are discussed. These results can be improved by preprocessing the data further by phase correction or phase synchronization, neutralizing the reverberation of the signals.

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Design and Development of Microcontroller based Maximum Power Point Tracker and Inverter for Small Power Applications

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Abstract - **Maximum Power Point Tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions and of the load electrical characteristics. A microcontroller based MPPT has been developed for a stand-alone small power PV system. A Buck type DC/DC converter is used to control the power output from solar module. This MPPT System is then used as a charge controller to charge and monitor a storage battery. AC loads are fed from the battery by using an Inverter. The inverter presented in this paper is of Square Wave, Voltage Source Inverter type which can be used in simple household applications. The Experimental results are presented and discussed.**

Key Words: **Solar PV, MPPT, Microcontroller, Perturb & Observe method, square wave Inverter**

1. INTRODUCTION

Fossil fuels are available for short-term and non-eco friendly energy sources; consequently, the use of alternative sources such as solar energy is becoming more wide spread. The use of photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management [1]. Owing to their high initial cost, PVSCs have not yet been fully an attractive alternative for electricity users who are able to buy cheaper electrical power from the utility grid. However, they can be used extensively for lighting, water pumping and air conditioning in remote and isolated areas, where utility power is not available or is too expensive to transport. In India there are about 300 clear sunny days in a year and solar energy is available in most parts of the country, including the rural areas. With the growing demand for renewable sources of energy, manufacturing of solar cells and photovoltaic arrays has advanced dramatically in recent years. Its efficient usage has led to increasing role of photovoltaic technology as scalable and robust means of harnessing renewable energy.

1.1 Need for MPPT

Photovoltaic modules have a very low conversion efficiency of around 15%. Besides, due to the temperature, radiation and load variations, this efficiency is highly reduced. In order to ensure that the photovoltaic modules always supplying the maximum power as possible and dictated by ambient operating conditions, a specific circuit known as Maximum Power Point Tracker (MPPT) is required, which is an electronic control system used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions and of the load electrical characteristics [1], [2], [3].

2. BLOCK DIAGRAM OF STANDALONE PV SYSTEM

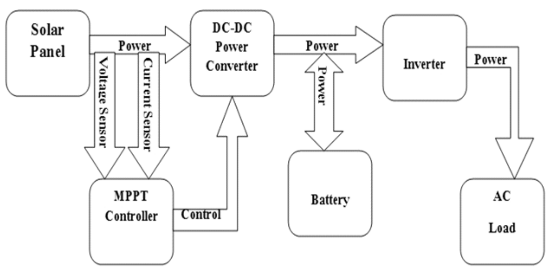


Fig. 1. Block Diagram of Standalone PV System

Fig.1. Shows the overall block diagram of the proposed PV system. A Buck-type DC/DC converter is used to interface the PV output to the battery and to track the maximum power point of the PV array. Battery is acting as load on the PV module. The inverter converts DC into AC which can be used for lighting loads [4], [7].

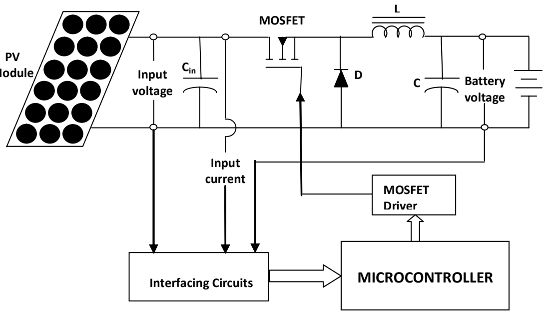


Fig. 2. Detailed Block Diagram of MPPT Unit

Detailed block diagram of the proposed PV system is shown in Fig. 2. The converter power switch consists of power MOSFET. The flyback diode is of a fast switching type. The output inductor is wound on a ferrite-core. The inductor together with the input and output capacitor values is calculated according to the procedure described in the section 4. In the configuration of Fig. 2, a battery is used as load for PV array. For given atmospheric conditions, the battery charging current depends on the PV output power and the battery voltage. The battery voltage increases according to the charging level and it is monitored to prevent overcharging [7].

The control unit consists of:

- **Arduino UNO-Microcontroller** board based on **Atmega328.**
- **Interface circuits** which comprise of sensors and signal conditioners connected to the Microcontroller A/D converter.
- **IC driver** for the power MOSFET.

The power consumed by the MPPT unit is about 1 W and it is supplied by the solar panel itself.

3. SENSOR AND INTERFACE CIRCUITS

3.1. Voltage Sensor

In order for the MPPT controller to measure the voltage of the Solar panel, two resistors, R_1 and R_2, are employed in parallel with the Solar panel to act as a voltage divider. The allowable voltage range for each ADC channel of the MPPT controller is 0-5 V dc. Therefore, the voltage across R_2 (which serves as a scaled-down representation of the Solar panel's voltage) should not exceed 5 V. In order to avoid the reduction in efficiency, the diverted current I_d should be as low as possible. The values of resistors R_1 and R_2 are calculated to be R_2(max)= 250 kÙ and R_1 = 800 kÙ

Setting the nominal value of V_{R2} to be 4 V, the values of R_1 and R_2 are 820 kÙ and 180 kÙ respectively. In the same way, the values of resistances for the Battery Voltage sensing circuit were calculated, but considering the nominal battery voltage to be 6 V. The values of R_1 and R_2 for the battery voltage sensor were found out to be 560 kÙ and 180 kÙ.

1.1. Current Sensor

To measure the current provided by the Solar panel, a single resistor (R_{sense}) is placed in series between the Solar panel and the DC/DC converter. The voltage across R_{sense} is fed into an AD8215, current shunt monitor IC manufactured by Analog Devices whose output voltage is then fed into an ADC driver circuit (op-amp in a voltage follower configuration that feeds into a low-pass filter) before being delivered to the ADC channel of the MPPT controller.

As stated previously, the allowable voltage range for each ADC channel of the MPPT controller is 0-5 Vdc. Therefore, the output voltage of the AD8215 current sensor (which serves as an equivalent voltage representation of the Solar panel current) should not exceed 5 Vdc. The value of R_{sense} has been calculated as .

Setting the nominal value of V_{out} to be 4 V, the value of R_{sense} is found out to be 0.1 Ù. With the chosen value of R_{sense} value (which is 0.1 Ù), the voltage drop across R_{sense} resistor in the worst case condition (i.e with maximum current, I_{sc}=2.43 A) is 0.243 V which is quite acceptable.

In order to condition each of the voltage signals sent to the ADC channels of the MPPT controller, Texas Instruments OPA340 model single supply op-amps are used in voltage follower configurations with each of their outputs fed into a low-pass filter. The voltage and sensor circuits along with their corresponding ADC driver circuits are all combined to form the "sensing circuit" for the MPPT system.

4. DESIGN OF BUCK CONVERTER COMPONENTS

4.1. Selection of Inductor and Capacitors values

In this paper USP37 solar PV module is used for analyzing the MPPT and Inverter circuits. In table.1 the parameters of the USP37 are given at 25°C operating temperature and 1000 W/m^2 Irradiation.

Tab.1. Parameters of USP37 solar PV module

Maximum power (P_{max})	37 Wp
Open Circuit Voltage (V_{om})	21.5 V
Maximum power point voltage (V_{pvm})	17.1 V
Short circuit current (I_{om})	2.43 A
Maximum power point current (I_{pvm})	2.17 A

Depending on the load and the circuit parameters, the inductor current can be either continuous or discontinuous before the end of the switching period. The inductor value required to operate the converter in the continuous conduction mode is calculated such that the peak inductor current at maximum output power does not exceed the power switch current rating. Thus, the inductor, input capacitor and output capacitor values are calculated by using the equation (1), (2), and (3) respectively.

$$L \geq \frac{V_{om}(1-D_{cm})}{r f_s |\Delta} \quad (1)$$

$$C \geq \frac{D_{cm} I_{om}}{r f_s V_{om}} \quad (2)$$

$$C_{in} \geq \frac{D_{cm} I_{om}(1-D_{cm})}{r f_s I_{pvm} R_{pvm}} \quad (3)$$

where, r – output voltage ripple factor

f_s – switching frequency

V_{om} – maximum DC output voltage

I_{om} – maximum DC output current

D_{cm} – duty cycle at maximum converter output power

I_{lm} – Peak to peak ripple of inductor current

I_{pvm} – Solar panel current at maximum power point

V_{pvm} – Solar panel voltage at maximum power point

The values of inductor, input capacitor and output capacitor for the buck converter are found as 0.1467 mH, 24 µF, and 86 µF respectively.

When Buck converter is used in PV applications, the input power, voltage and current change continuously with the atmospheric conditions, thus the converter conduction mode changes since it depends on them. Also, the duty cycle is changed continuously in order to track the maximum power point of the PV array. The choice of the converter switching frequency and the inductor value is a compromise between converter efficiency, cost, power capability and weight. For example, the higher the switching frequency, the lower the inductor core size, but the power switch losses are higher. Also, by using a large value, the peak-to-peak current ripple is smaller; requiring lower current rating power switches, but the converter size is increased substantially because a larger inductor core is required.

4.2. MOSFET

The power switching device chosen is Power MOSFET **IRFZ44N**. IRFZ44N is an N channel enhancement mode standard level field-effect power transistor in a plastic envelope using '**trench**' technology. The device features very low on-state resistance and has integral zener diodes giving **ESD** protection up to 2 kV. It is intended for use in switched mode resistance power supplies and general purpose switching applications.

5. SQUARE WAVE INVERTER DESIGN

Fig.3. shows a half-bridge voltage source Inverter. The switches can be bipolar, MOS transistors, or thyristors. The circuit works by turning switch 1 ON, the output voltage is then the positive half-cycle, meaning that it will be Vs/2. To get the negative half-cycle, switch 2 is turned ON and switch 1 is turned OFF. The order of this is actually reversed; switch 1 must be turned OFF first in order to avoid any short circuit. Voltage outputs of this simple half-bridge Inverter are shown in Fig. 3. If the load is always inductive, the load current, i_{on}, will lag the voltage waveform, also shown in Fig. 3. It is shown that the current is sometimes negative when the voltage is positive [5], [6].

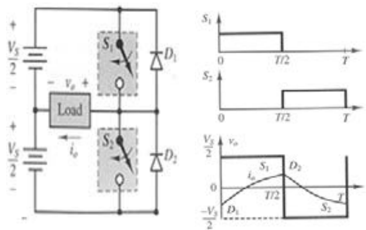


Fig. 3. Half Bridge Voltage Source Inverter-Configuration and Waveforms

The diodes function to conduct the load current whenever it is opposite polarity to that of the voltage. If the diodes were not present then the load current would not exist. Fig. 3. also shows that D_1 is conducting during the first half of the cycle and D_2 during the second half.

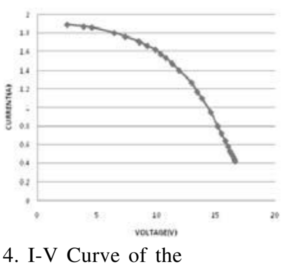
CD 4047 is a low power CMOS astable/bistable multivibrator IC. It is wired as an astable multivibrator producing two pulse trains of 10 ms which are 180 degree out of phase at the pins 10 and 11 of the IC.

When pin 10 is high, upper MOSFET Q1 conducts and current flows through the upper half of the transformer primary which accounts for the positive half of the output AC voltage. When pin 11 is high, lower MOSFET Q2 conducts and current flows through the lower half of the transformer primary in opposite direction and it accounts for the negative half of the output AC voltage.

Specifications

- The square wave Inverter (voltage source half bridge configuration) provides uninterrupted supply with an output of 230 V, 100 W and can drive a load of up to 2 A.
- It can be used to supply power to lamps (fluorescent and incandescent) with a power rating of 100 W or lesser.

6. EXPERIMENTAL RESULTS



4. I-V Curve of the Solar Panel

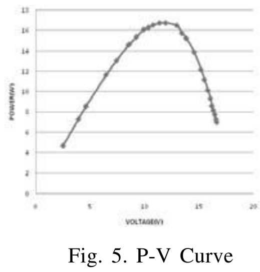


Fig. 5. P-V Curve of the Solar Panel

Fig.6.Maximum Power Point Tracker Circuit

Fig.7.Maximum Power Point Tracker Circuit with Solar Panel

The Experimental set up for the developed Maximum power point tracking system is shown in Fig.6 and Fig.7. I-V and P-V curves are plotted from the experimental readings taken from the Solar Panel USP37 by connecting a resistive load on a particular day, which are shown in Fig. 4. and Fig. 5. respectively. From Fig.4., it can be seen that the maximum output power of the solar panel is 16.74 W which corresponds to intensity of 104500 LUX. The proposed MPPT system is then tested under different light intensities and the data obtained are tabulated in Table.2. With the proposed system, the output power of the solar panel is found to be in the range of 16.49 – 16.62 W under different light intensities, which shows that the proposed system always follows the maximum power point of the solar panel.

Table.2 Solar PV Characteristics with MPPT

S. No	Intensity (LUX)	Voltage (V)	Current (A)	Power (W)
1	104500	10.02	1.65	16.53
2	104300	10.07	1.65	16.62
3	104400	10.08	1.64	16.53
4	104500	10.09	1.64	16.55
5	104300	10.12	1.63	16.49
6	104400	10.10	1.64	16.56
7	104400	10.12	1.63	16.49
8	104300	10.14	1.63	16.53

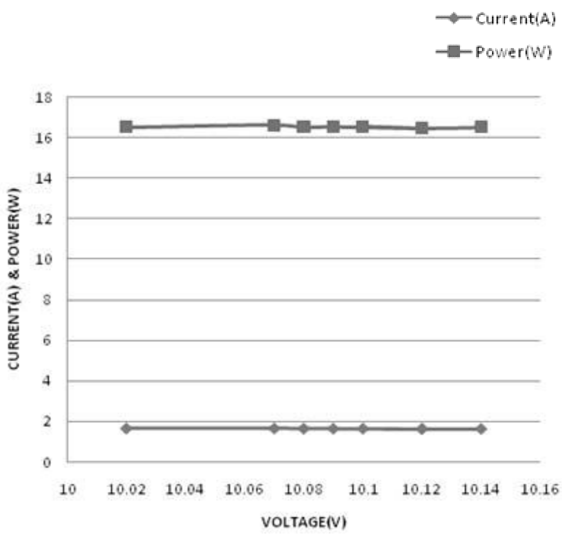


Fig.8. I-V and P-V Curves for the proposed system

Fig. 8 shows the power output from the solar panel with MPPT. It clearly indicates that the power output from the solar panel is maximised by the DC-DC Converter and the battery is getting charged continuously. Under varying temperature and irradiations the developed MPP System is tracking the maximum power point always. The experimental set up of the Inverter circuit is shown in Fig. 9. The inverter circuit was also tested with 8 W CFL and the output voltage is found to be 210 V and the output square waveform is obtained in CRO which is shown in Fig.10. The whole set up was integrated and tested under varying environmental conditions with 8 W CFL as load.

Fig. 9. Practical Inverter Circuit Operation

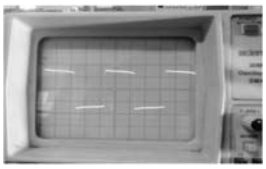


Fig. 10. Inverter Output Square waveform in CRO

7. CONCLUSION

In this paper, a low-cost, low-power consumption MPPT system for battery charging has been developed and tested. The system consists of a high-efficiency, Buck-type DC/DC converter and a microcontroller-based unit which controls the duty cycle for DC/DC converter directly from the Solar Panel output power measurements. Experimental results show that the proposed MPPT control system always follows the maximum power point under varying solar characteristics.

The proposed control unit was implemented on Arduino UNO-Microcontroller board based on Atmega328 microcontroller since it permits easy system modifications. Total power consumption of the control unit is less than 1 W. Furthermore, the MPPT System is coupled with Half Bridge Voltage Source Inverter designed using CD 4047 is a low power CMOS actable/constable multivibrator IC, which provides an uninterruptible power supply for household applications. The inverter circuit was tested and found to be operated correctly which gives square waveform output, which can be used for small power applications.

The whole proposed system can be used as energy saving standalone power system. Thus, a simple, low cost, efficient Solar PV system has been developed for small power applications. The proposed system can be combined in a hybrid system where the microcontroller performs simultaneously the MPPT control of more than one renewable energy source. As an extension the artificial intelligence techniques such as Fuzzy, Neural, Particle swarm optimisation or Genetic algorithm can be used for implementing MPPT instead of Perturb and Observe method and the results may be compared.

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SMART DISTRIBUTION SOLUTIONS: SAFE & RELIABLE

Introduction

The quality of the electricity supply has always been a point of major interest. Worldwide there is an increasing concern about Power Quality. The Indian scenario on one hand is experiencing ever growing infrastructure & social developments demanding for reliable & uninterrupted power supply and on the other side privatization of electricity distribution has changed the market trends tending towards more competition, reduced costs, accountability for non-delivered kWs and kWhs, less maintenance, environmental aspects, operator safety, better customer orientation and satisfaction etc. Both the technology and the market driven changes tend to keep the electricity distribution always on look for innovative and SMART solutions. This article mainly focuses on one such SMART product Ring Main Unit (RMU) and the emerging trends in RMU application.

Siemens RMU type 8DJH ST

Market Trends

Importance & dependability of electricity is already proved in day to day functioning of mankind. Although the future is gearing up for more efficient and reliable energy the current situation calls for stronger and sustainable grids in-turn giving more emphasis on reliable RMUs.

Technical needs

- Day by day increasing load of the distribution network.
- Simple and safe operation of the switchgears.
- Optimization of load flow.
- Compatibility with SCADA systems for integration into smart grids.
- Low maintenance or preferably maintenance free.
- Compact design by virtue of SF6 medium as insulation.

Nowadays Vacuum is the preferred switching technology for newly developed medium voltage circuit breakers. As a need for maintenance free with Vacuum, the switchgear designs nowadays evolve into fixed Vacuum Circuit Breaker designs with SF6 gas as an insulating medium. This evolution results in a higher availability against lower costs, compared to the conventional Air Insulated withdrawable designs.

Switching in Vacuum

Siemens is the pioneer in the Vacuum technology and has been a leading manufacturer of Medium Voltage Vacuum Circuit Breakers. The Vacuum technology has evolved from old days pinching technology to latest hermitically sealed Vacuum interrupter. This change has further made the Vacuum Interrupter more reliable than before.

Siemens Vacuum Interrupter

The Siemens Vacuum Interrupter contacts are designed with Axial Magnetic Field (AMF) principal because of the negligible contact erosion and the excellent switching performance at low and high fault currents. The benefit of negligible contact erosion makes this type of interrupter particularly suitable for use in non-withdrawable switchgear systems and sealed systems, because replacement of the interrupter during the technical life cycle of the unit in not foreseen. This further reinforce the claim of maintenance free RMUs.

Safe & reliable switching

The safety of the operators & maintenance personal is also a very important aspect of dealing with any medium voltage switchgear and modern days Gas Insulated RMUs are no exception to the same. The RMUs type tested with the latest IEC 62271-200 comply with the latest safety aspects of the operators working on the switchgear. One of the most important criteria's for the human safety is internal arc fault occurring into the switchgear in service. Latest IEC 62271-200 clearly defines the internal arc requirements and the qualifying criteria's. The past situation with IEC 60298 was

1. Classification based on design variations: Metal- clad, compartmented and cubicle
2. Type testing classified as Normal type and special type
3. No clear guidelines for Internal arc testing and qualification criteria

The present situation with latest IEC 62271-200 is

1. Classification based on purpose
2. Type tests classified as Mandatory and optional
3. Non ambiguous internal arc testing requirements and qualification criteria

Siemens 8DJH ST, SMART design

The area of application of the new switchgear is the secondary distribution network and compact substations for transformer switching.

Technical ratings for 12kV application

- Rated voltage 12kV
- Rated frequency 50Hz
- Rated busbar current 630A
- Impulse withstand voltage 75kV/95kV*
- Power frequency withstand 28kV
- Rated short time withstand 20kA/3sec
- Rated peak withstand current 50kA
- Internal arc resistant 20kA

* Upon request

Circuit-breaker:

- Circuit breaker rated current 250/630A
- Rated breaking current 20kA/3sec
- Rated short circuit making current 50kA

Load-break switch:

- Rated current 630A
- Rated breaking current 630A
- Rated short circuit making current 50KA

Self-Powered Protection

The 8DJH ST is equipped with Self-powered protection relay devices (Electronic/Numerical) designed and optimized to keep the protection simple and economic. The design has been focused on high level of quality and effective over current & earth fault protection for distribution transformers as small as 150kVA. The relay needs no external power supply but is energized from the compatible current transformers and has independent characteristics. Some of the key features of relay are

- Including self test circuit, the complete chain of protection can be tested.
- Settings via laptop with dedicated software or a hand held device
- IDMT Characteristics

Smart solution for Intelligent network

In current scenario the switchgear in secondary distribution networks are mainly hand operated resulting in long lead time for restoring the power supply, depending on the density of the network and the local conditions like long distances or areas inaccessible due to heavy traffic. The new 8DJH ST comes in a standard version of manual operated VCB & Load break switches however it can also be upgraded to completely remote controlled unit even at a later date at site. This upgradation can be achieved without any power shutdown or outage on the unit under service.

Sealed for life design

The medium voltage distribution network in India is subject to a number of external influences during its total life cycle. Issues of aging cables, connections & switchgear itself must be considered while designing the network. As a switchgear manufacturer only the last item is dealt with in this article. The ideal switchgear deals with aging and slow deterioration of important medium voltage parts and mechanism by avoiding long term influences. The "fit & forget" principle can be the perfect solution for minimizing future disturbances in the network without paying attention to the switchgear components at all. Apart from the SMART design features 8DJH ST also deals with the issue of primary live switching parts by way of hermitically sealing them in corrosion free high grade stainless steel tank encapsulated with SF6 gas. This ensures all the switching parts are free from any of the climatic interferences making the switchgear maintenance free for lifetime.

Conclusions:

- Market driven changes will result in higher power quality/reliability demands, against no or minimal extra lifetime costs of the equipment, achieved in the described RMU by its increased availability. Also the price of non-availability of energy in the distribution network will increase by virtue of strict supply norms.
- Including majority of SCADA compatible RMUs in the network will able better control of the distribution. The viability of such intelligent RMUs will increase by the increasing demand of Smart Grid.
- The design of RMUs with "fit & forget" principle leads to environmentally and economically acceptable solutions.
- The Siemens 8DJH ST RMU is fit for the current & future network needs and is fully type tested as per the latest IEC 62271-200.

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- Remember Thou art a member of a team and the achievement of the team is thy own success.
- Thou shalt not malign thy co-professionalists.
- Thou shalt strive for the advancement and dignity of thy juniors in the profession.
- Thou shalt strive for the welfare of the community.
- Thou shalt enlighten the community with the correct aspect of Engineering/Technological activities.
- Thou shalt endeavour to develop a dignified status in the society.
- Thou shalt strive by conduct and character to be a worthy citizen of the Motherland.

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Horse Leap

“In the area of energy planning, our state should not need to repeat the mistakes of highly industrialised countries in creating an energy infrastructure based on fossil fuels, but ‘jump’ directly to renewable energy sources and more efficient technologies.

We should perform a ‘horse leap’ – where we can skip less efficient, more expensive or more polluting technologies and industries and move straight to superior and advanced ones.”

“We do not inherit the Earth from our Ancestors; we borrow it from our Children.” - a proverb

Waste to electricity plant

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