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Editorial

The Indian Power Sector and Smart Grid

India operates the 3rd largest transmission and distribution network in the world, yet faces a number of challenges such as inadequate access to electricity, supply shortfalls, huge network losses, poor quality ,reliability, rampant and theft.

The magnitude of capacity being added each year has increased manifold when compared to previous planning periods. Also, with the use of new and more advanced technologies, efficiency of thermal power plants has been improving and emission levels falling. Operational requirements related to scheduling and dispatch is driving the implementation of automation across the power system and for the generators. All new plants now have sophisticated operational IT systems and the existing generation fleet is slowly upgrading to match.

Renewable Energy (RE) based electricity generation has gained prominence over the years. Several fiscal and policy measures have been introduced to promote RE. On an average, over 3000MW of RE installed capacity has been added every year with major contribution from the wind energy segment.

The transmission sector in India is moving towards higher voltage levels of 1200kV and is introducing a higher level of automation and grid intelligence. Significant technological advancements such as increasing the capacity of transmission corridors through the use of Static VAR compensation and re-conductoring of lines using High Temperature Low Sag (HTLS) wires are also being taken up.

There is an urgent need to bring in new technologies electricity distribution sector in India

The exigency for Smart Grids in India emerges from the challenges that the Industry is presently facing. The evolution towards Smart Grid would address these issues and transform the existing grid into a more efficient, reliable, safe and less constrained grid that would help provide access to electricity to all.

Smart grids will make use of new design concepts and advanced materials in system components like transformers and circuit breakers to improve efficiency, safety and operational performance. Widespread use of power electronic devices will help maximize performance of existing assets and make the grid more resilient in the event of disruptions. The Smart Grid represents an unprecedented opportunity to move the energy industry into a new era and will contribute to our economic and environmental health. The benefits associated with the Smart Grid include: More efficient transmission of electricity, Quicker restoration of electricity after power disturbances, Reduced operations and management costs for utilities, and ultimately lower power costs for consumers, Reduced peak demand, which will also help lower electricity rates, Increased integration of large-scale renewable energy systems, Better integration of customer-owner power generation systems, including renewable energy systems and Improved security

Electrical systems will undergo a major evolution, improving reliability and reducing electrical losses, capital expenditures and maintenance costs. The smart grid is the future for electrical systems, as it is designed to meet the four major electricity requirements of our global society: capacity, reliability, efficiency and sustainability.

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Contents

A New Technology for Green Energy

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Availability of sufficient energy, food, and waste disposal facilities are highly essential for the development of the community. In addition to these, sanitation is also one of the most important factors for having a healthy life style. Due to various reasons most of the peoples living in the villages, coastal areas and slum areas have no sufficient sanitation facilities.

When slums were formed in the banks of water bodies, it is the usual practice that the discharges from the toilets are directly connected to the water bodies. This will lead to severe water pollution including the spreading of water related diseases. It is high time to undertake corrective measures to overcome this situation. Otherwise the precious drinking water sources including ground water will be contaminated and the availability of drinking water will become a big problem.

Due to thick population in urban areas, the drainage lines are overloaded and the related issues are frequent and common. The existing drainage facilities are not quite sufficient to meet the requirement compared to the growth in the population. Pre treatment of excreta before passing to the public sewage system is also one of the best options to mitigate this issue to a considerable extent.

The scientific disposal of human excreta is a major problem. Many remarkable achievements to improve the sanitation have already been taken by government bodies as well as by many national and international Organizations. A good number of public toilet complexes and individual toilets have been constructed with automatic / electronic system. But almost all the toilet complexes are having traditional septic tanks only. Such septic tanks may be those constructed at the site or pre fabricated ones. An exhaust pipe is seen connected with all septic tanks to release the gas generated inside the septic tanks. The gas generated from the septic tanks will be mixed with the atmosphere due to this arrangement.

As per scientific studies it is understood that human excreta discharged by an adult person is capable of producing 29 – 30 litres of Biogas every day. It is estimated that the excreta of an average family having 5 members will produce about 54 Cum of Biogas per year. This is equivalent approximately to 27 kg of LPG. In other words, if we can capture this biogas with the help of aa anaerobic digester, it will be helpful for the conservation of LPG in urban areas and fire wood in rural areas.

Biogas is a good source of Green Energy which can be used to meet all the requirements of energy needs. Due to unscientific design and construction of septic tanks, facilities are not sufficient enough for capturing the biogas from the septic tanks.

If we allow to release the biogas from septic tanks to the atmosphere, it will cause severe environmental pollution problems because of the presence of the Methane, which is the major content in the biogas.

The excreta of 35 peoples will be producing about 1000 liters of biogas (1 cum) every day. The main content in the Bio Gas is methane, which is 22 times more dangerous than Co2. The biogas produced in one year from the excreta of 35 peoples will be equivalent to the pollution caused by 3.5 metric tons of Co2. From this we can imagine the quantity of methane being emitted in a country like India, having a total population of around 120 crores of peoples.

Considering the potential of capturing of methane in the form of Biogas, It is high time for developing a compact device to capture methane from human excreta. Many schemes are available in the form of toilet linked biogas projects, to capture the bio gas from human excreta. Due to various reasons, all these schemes are not picking-up in accordance with the potential available. One of the main reasons attributable for this is that the level of the out let pipe line from the toilets to the existing septic tank is very deep in the ground. So the procedure of connecting the existing toilet to the bio gas plants is not quite easy and practicable. So many people are not willing to construct toilet linked bio gas plants. Lack of awareness of the peoples is also one of the factors for the non cooperation of the peoples in this regard.

Anaerobic Septic Tank

Based on incessant and continues research for years, we developed a new generation of anaerobic septic tank, which is suitable to link existing toilets and the newly constructed ones. The patent registration work of this anaerobic digester had already been completed.

This anaerobic septic tank is working under biomethanation process. Through the microbial action inside the anaerobic digester the solid content in the excreta will be converted in to biogas. It is a compact device made of Fiber glass Reinforced Plastic (FRP). Installation time is also very less compared with other systems. The Bio gas produced from the anaerobic septic tank can be collected in an external balloon, or the gas collector of a floating dome gas model bio gas plant.

For a 5 member family, a 1000 litre anaerobic septic tank will be sufficient. This volume takes in to consideration of the water discharged from the toilet. The strength of the body of the anaerobic septic tank is designed to withstand the ground pressure. To create anaerobic condition, a water seal is provided in the top cover of the digester. This cover is designed with a special lock system to simplify the installation, activation, operation and maintenance of the device. During the operation of anaerobic septic tank, it is advisable to use mild toilet cleaners instead of strong chemicals and acids to clean the toilets. The continuous use of strong chemicals to clean the toilets will distroy the presence of microbs in the septic tank. This will reduce the efficiency of the system. The expected life span of an anaerobic septic tank will be more than 15 years.

Different capacities of prefabricated anaerobic septic tanks are available to meet the requirements of all categories of individuals, families and housings communities etc. The bio gas generated can be used for cooking, lighting and for the generation of electricity for institutional and community applications.

Introduction of anaerobic septic tanks will completely be of environmental friendly system. It will also help to generate green energy without any recurring expenses.

The Swach Bharath Mission of the Prime Minister of India envisages better sanitation for all the peoples in the country within a few years. Under this programme the construction of toilet is one of the important aspects. Along with the toilets septic tanks or drainage system are the unavoidable part. If anaerobic septic tanks can be included along with the toilet construction it will help to improve the sanitation and also help to produce biogas at the same time.

In consideration of the atmospheric pollution, and the increase in demand for energy, an initiative has to be taken on the part of Government to provide necessary support to the public, to construct anaerobic septic tanks, along with all existing and new toilets.

Those who are interested to undertake commercial production of this Anaerobic Septic Tank can consult BIOTECH, a Kerala based R&D organization and consultant of renewable energy. BIOTECH is providing all technical support to introduce anaerobic septic tanks to all categories of the public in the community.

Dr. A. Sajidas

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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ENGINEER'S DAY

September 15

Bharat Rathna
Sir MOKSHAGUNDAM VISVESVARAYA
1860-1962

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.

Optimum Resistance Selection Method for Resistive Fault Current Limiter used to Restore Original Relay Protection Scheme in Presence of Distributed Generation

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Abstract

Directional overcurrent relays are being commonly used for the protection of distribution networks. These relays should be properly coordinated in order to prevent the maloperation of primary and backup relays and thus improve the reliability of the power system. In this paper, for solving the directional overcurrent relay coordination problem Genetic Algorithm is used. When a distributed generator (DG) is connected to such a system and if a fault occurs, they act as a source of fault current. This can cause disturbance to the original relay protection scheme and can cause maloperation of primary and backup relays. The fault current contribution of DG can be limited by placing fault current limiter (FCL) in series with the DG. This paper proposes a new method, based on optimization using Genetic Algorithm, for finding the optimum resistance of resistive FCL required to restore the original relay setting. The effectiveness of proposed method in the presence of single and multiple DG existence is illustrated.

1. Introduction

Power system is subjected to different types of faults and relays are the major sensing equipments which provides tripping signal to the circuit breakers to isolate fault. For the protection of distribution networks, directional overcurrent relays are used. Directional overcurrent relay operates only when current through its operating coil exceeds a specific value in a specified direction. As far as protection engineers are concerned, directional overcurrent relays should be properly coordinated in order to prevent system failure.

The importance of relay coordination arises due to the fact that power system is divided into different zones of protection and each zone in a power system is protected by a primary relay and a backup relay. Primary relay acts as the first line of defence and backup relay acts as the second line of defence, that is, when a fault occurs the primary relay should act first to clear the fault. The backup relay should operate only when primary relay fails. Thus there should be a minimum time interval between the operation of primary relay and backup relay. To ensure this condition relays should be properly coordinated.

Many optimization methods have been used for solving the directional overcurrent relay coordination problem. The coordination problem is generally formulated as a linear programming problem. In linear model, only the time multiplier setting is minimized. The pickup current settings are fixed at values between the maximum load current and minimum fault current [1] – [3]. In [2] and [3] optimum coordination is determined considering configuration changes in the network. [4] uses additional constraints in the directional overcurrent relay coordination problem to tackle the sympathy trips which deals with conditions where other relays operate before the designated primary relay. A method of simultaneously optimizing all the settings of the directional overcurrent relay, in a nonlinear environment by sequential quadratic programming method has been presented in [5]. Genetic Algorithm, Evolutionary Algorithm and Particle Swarm Optimization have been used in [6] [8] respectively to find the optimum setting of relays. In this paper, Genetic Algorithm(GA is the optimization method used to solve the relay coordination problem.

Distributed generators are electric power generating units which feeds power into the distribution system at the point of use. There generating capacities usually lie in the range of3

kW to 50 MW. They are popular mainly due to the fact that power loss due to long distance AC transmission lines can be eliminated if generators are placed close to the load. They are used to meet the increasing load demands without redesigning the transmission lines. Distributed generators mainly use renewable resources and thus they prevent pollution, reduce green house effect, help in saving fossil fuels, reduce fuel cost and ensure energy security.

When a distributed generator is connected to the grid and if a fault occurs at the grid side, distributed generator will act as a source of fault current thus the net fault current in the line increases. This can sometimes reduce the coordination time interval between the backup and primary relay or in certain cases the operating time of backup relay may become lesser than the primary relay. This affects the original protection relay coordination and leads to malfunctioning of protective devices. This also necessitates the upgradation of circuit breakers. But upgrading circuit breakers each time when a new distributed generator is installed, is not a cost effective method. Another method is to disconnect the distributed generator following a fault at grid side. But this involves synchronization issues.

In order to reduce the fault current contribution of distributed generator during fault, fault current limiter is an effective solution. Fault current limiters are devices placed in series with the power system to be protected. They offer zero impedance during normal operation but introduce enough impedance during fault so that the fault current flowing through them is limited. Many studies show that fault current limiters can limit the fault current contribution of the distributed generator and thus maintain the original protection coordination [9]- [11]. [11] suggest that the optimum location for placing fault current limiter is near the distributed generator. In [9] a control scheme for determining the impedance of a fault current limiter connected to a distributed generator is suggested. It also illustrates that resistive FCLs can restore the original relay settings with smaller resistance values than inductive FCLs which require higher inductance. But by the above method, optimum value of FCL impedance cannot be determined. Also for the multiple DG scenario, the above method uses same impedance value for the FCLs in series with the DGs, which is not a cost effective method.

In this paper, a new method based on optimization using Genetic Algorithm is used for finding the optimum resistance of resistive FCL, required to restore the original relay setting. The effectiveness of proposed method in the presence of single and multiple DG existence is also illustrated.

2. Relay coordination problem

For any distribution system, the aim of the relay coordination problem will be to minimize the sum of the operating time of the primary relays. If n is the total number of relays, then the objective function is given by

$$minz = \sum_{i=1}^{n} t_{i,f}$$

where

$t_{i,f}$ operating time of the primary relay for a fault at f n number of relays

The constraints for the relay coordination problem are:-

Limits on plug setting of the relay : The plug setting (PS)of the relay should be selected in such a way that it should not operate for small amount of overload current and at the same time it should be able to detect even the smallest fault current. As a thumb rule, the minimum and maximum value of plug setting can be fixed as 1.25 and 2 times the maximum load current seen by the relay [9].

$$PS_{i,min} \leq PS_i \leq PS_{i,max} \quad (2)$$

where

$PS_{i,min}$ minimum value of the PS of the relay

$PS_{i,max}$ maximum value of the PS of the relay

Limits on time multiplier setting of the relay : The time multiplier setting(TMS of the relay

$$TMS_{i,min} \leq TMS_i \leq TMS_{i,max} \quad (3)$$

where

$TMS_{i,min}$ min minimum value of the TMS of the relay R_i

$TMS_{i,min}$ max maximum value of the TMS of the relay R_i

Constraint on coordination time : Each zone in and a backup relay. The fault current in a given line is sensed by both the primary relay and backup relay. The backup relay should operate only when the primary relay fails. To ensure this, there should be a minimum time interval between the operating time of the backup relay and that of the primary relay. This time interval known as the coordination time interval(CTI is the sum of the operating time of the circuit breaker associated with the primary relay and the overshoot time. In this paper, CTI is taken to be 0.2 sec.

$$t_{j,f} - t_{i,f} \geq \Delta t \quad (4)$$

where

$t_{j,f}$ operating time of the backup relay R_j for fault at f $t_{i,f}$ operating time of the primary relay for fault at f Δt CTI

Relay characteristics : The operating time depends on TMS and PS. In this paper, a nonlinear overcurrent relay characteristics with λ and γ equal to 0.14 and 0.02 respectively is used.

$$t_i = \frac{\lambda(TMS)}{\left(\frac{I_{relay}}{PS}\right)^{\gamma} - 1} \quad (5)$$

where

t_i operating time of the relay R_j for a fault at f I_{relay} fault current seen by the relay

3. Genetic Algorithm

GA is a popular optimization technique used when the problem is highly nonlinear. It is based on arwin' s theory of "survival of the fittest''". It starts its operation by creating a set of variables. Each ariable is expressed in the form of binary numbers, 0 and 1. Then these variables are arranged side by side in the form of a string. This string is called a chromosome. A group of chromosome is called population. Thus Ga begins its operation by creating a random initial population.

GA then performs three operations reproduction, crossover and mutation. In the process of reproduction, the population is sorted according to the fitness value of the chromosome. The chromosome with higher fitness value are selected for mating. These selected chromosomes are called parent chromosome. After reproduction, next operation performed is crossover. In this process, two new chromosomes called offsprings are created from two parent chromosomes by combining a part of the information from each. Then mutation is performed where at a randomly selected location within the chromosome, a binary digit may be changed from 0 to 1 and vice versa. Then the current population is replaced with new chromosomes to form the next generation. This entire process is repeated till the number of generations exceed the maximum number of generations.

4. Proposed Method for Selection of Optimum FCL Resistance

The idea behind using the FCL in series with he DG, is to introduce an impedance in series ith the DG, during fault, so that the fault current contribution from the DG is limited. When the fault current contribution from the DG is imited, the original relay settings can be retained for the protection of the distribution system. For a distribution system with multiple DGs connected, there should be a FCL, in series with each of the DGs. The impedance of FCL is selected in such a way that the difference in operating time between the backup and primary relay pairs is greater than or equal to the threshold value of coordination time interval [9]. But it is not economical to have very high impedance value for FCLs. This necessitates the need for determining optimum impedance value of FCL which satisfies the coordination time constraint and at the same time is cost effective.

In this paper, resistive type FCLs are considered. The aim of the resistance selection problem should be to minimize the resistance of the FCL in series with the DG. Thus the objective function is to minimize the sum of the resistance of all the FCLs.

$$minz = \sum_{j=1}^{m} RFCL_j \qquad (6)$$

where

$RFCL_j$ resistance of the FCL connected to j^{th} DG

m number of DGs connected to the distribution system

Following are the constraints for the resistance selection problem:-

Constraint on coordination time : The difference between operating time of all the backup primary relay pairs should be greater than or equal to the threshold value of coordination time interval (0.2 sec). The operating time of the relay is calculated after fixing the value of TMS and PS at the original relay setting. The resistance of the FCL has an impact on the distribution system only during the fault. It has no effect during normal power flow. RFCL is included in the impedance matrix Zbus during fault.

This in turn will reduce the value of the fault current. The operating time of the relay depends on the fault current seen by the relay. Thus the operating time becomes a function of RFCL.

$$t_{j,f} - t_{i,f} \geq \Delta t \qquad (7)$$

where

$t_{j,f}$ operating time of the backup relay Rj for fault at f

$t_{i,f}$ ti;f operating time of the primary relay Ri for fault at f

Δt 4t threshold value of CTI (0.2 sec)

Limits on resistance of FCL : FCLs have a fixed resistance value once they are installed into the system. Thus the resistance of FCLs have a upper and lower limit. These limits have been taken between 0 and 100 pu.

$$RFCL_{j,min} \leq RFCL_j \leq RFCL_{j,max} \qquad (8)$$

where

$RFCL_{j,min}$ minimum value of the FCL's resistance connected in series with j^{th}DG

$RFCL_{j,max}$ maximum value of the FCL's resistance connected in series with j^{th}DG

5. Simulation and Results

The proposed method is tested on the distribution system of the IEEE 30 bus test system [12] shown in Fig. 1. The distribution system is fed from three primary distribution substations (132kV/ 33kV) at bus 10, 12 and 27. The system has 29 directional overcurrent relays having inverse definite minimum time relay characteristics. The DGs considered for test has a capacity of 10 MVA, 0.9 power factor lagging, synchronous type, with a transient eactance of 0.15 pu. Usually DG is connected to the distribution system through transformers. In this paper, a 10 MVA transformer with 0.05 pu transient reactance is considered.

The entire control schematic is shown in Fig. 2. First the relay coordination of IEEE 30 bus distribution system without DG is performed. In order to solve the relay coordination problem, a MATLAB code for performing load

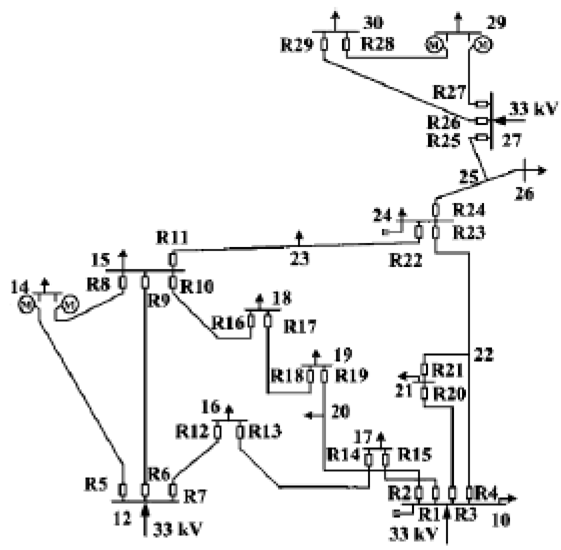

Figure 1. Distribution system of IEEE 30 bus system.

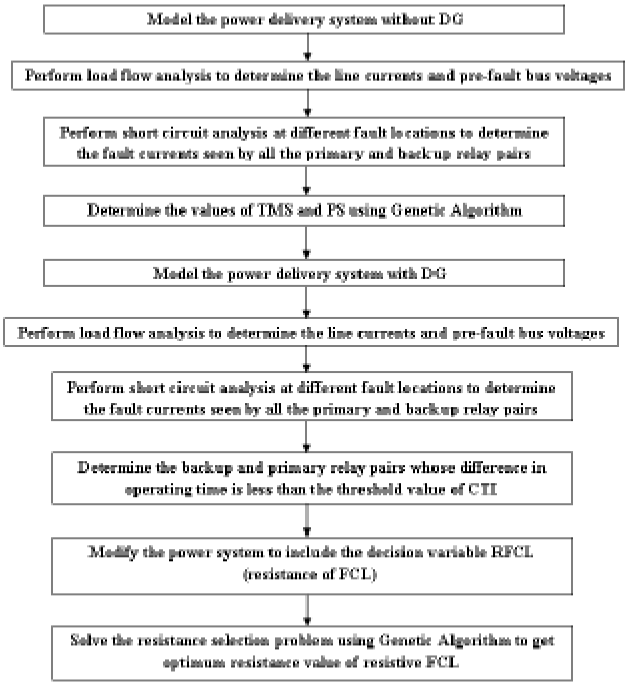

Figure 2. Control schematic

flow analysis and short circuit analysis is developed. Load flow analysis of the entire system gives prefault bus vosltages and line currents. Short circuit analysis gives fault currents flowing through the lines. Then the near end fault primary and backup relay currents are calculated. Then the directional overcurrent relay coordination problem is solved using the Genetic Algorithm function available in MATLAB ptimization toolbox. The obtained relay settings are shown in Table 1.

When a DG is connected to the distribution system, there

Relay	TMS	PS	Relay	TMS	PS
1	1.1824	0.9708	16	0.5563	0.8807
2	0.8852	1.3540	17	0.9094	0.4091
3	0.7425	2.5906	18	1.0146	0.4091
4	0.5233	1.2302	19	0.4452	1.0275
5	0.1000	0.7126	20	0.1000	1.9154
6	0.6554	2.6374	21	1.1149	0.3481
7	1.0566	1.0964	22	1.0822	0.3117
8	0.1000	0.1467	23	0.7064	0.8892
9	0.2517	2.6374	24	0.5265	0.2965
10	0.9545	0.8807	25	0.7306	0.7064
11	0.7572	0.8169	26	0.2280	1.0352
12	0.6035	1.0964	27	0.1000	0.5695
13	1.0381	0.5485	28	0.1000	0.3399
14	1.0523	0.5485	29	0.1000	0.6470
15	0.6261	0.9708			

Table 1. Time multiplier setting(TMS) and plug etting(PS) of relays

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
1	19	-0.288827	0.579835
1	20	-1.05051	0.200004
2	15	0.163070	0.697344
3	15	0.094691	0.575592
3	19	0.0933419	0.902297
2	20	-0.599962	0.644218

RFCL(pu) : 2.7090
ConvFCL(pu) : 3

Table 2. Restoration of miscoordinated relay pairs using RFCL for DG at bus 12 will be change in both the ormal power flow as well as in the fault currents flowing through the system. If the relay settings are kept fixed, some of the backup primary relay pairs will miscoordinate. Miscoordination can be in two ways; reduction in the coordination time interval between the backup and primary relay pairs or in certain cases the operating time of backup relay may become lesser than the operating time of the primary relay, that is, a negative CTI value.

The fault current contribution from the DG can be reduced by placing FCL in series with the DG. FCL offer high impedance, only when fault current flows through it. It has no effect on the normal power flow. In this paper, resistive FCL is considered. In order to implement the proposed method, RFCL(resistance of FCL) is considered as the decision variable and is included in the system only while performing short circuit analysis. Then the resistance selection problem is formulated using (6) as the objective function, (7) and (8) as the constraints. The problem is solved using Genetic Algorithm. The solution gives the optimum resistance value required to bring the coordination time interval of all the backup primary relay pairs above the threshold (0.2 sec).

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
6	12	0.199092	0.494795
7	9	-0.430402	0.200006

RFCL(pu) : 1.0055
ConvFCL(pu) : 2

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
1	19	-0.992457	0.200001
1	20	-0.642036	0.951904
2	20	-0.405088	1.37371
3	19	-0.652839	0.508509
4	19	0.166932	1.48808
7	9	-0.79821	0.517007
11	16	0.007261	0.631247

RFCL(pu) : 13.7019
ConvFCL(pu) : 14

Table 4. Restoration of miscoordinated relay pairs using RFCL for DG at bus 19

Table 2 shows the miscoordinated backup primary relay pairs and the extend of miscoordination, when the DG is placed at bus 12. Totally there are six miscoordinations. Three miscordinations are due to backup relay operating before primary relay (negative CTI). When the proposed method is applied, the optimum value of RFCL is 2.709 pu. The improved values of CTI is also shown.

In the method mentioned in [9], the resistance of FCL is gradually increased from a minimum value till the CTI of all the backup primary relay pairs become higher than the threshold value of CTI. If the value of resistance obtained by conventional method is represented as ConvFCL, then the value of ConvFCL obtained is 3 pu for the system with DG at bus 12. Similarly, Table 3 and 4, shows miscoordinated primary backup relay pairs, improved CTI values obtained by the proposed method, value of RFCL and the value of ConvFCL, for single DG operation at buses 10 and 19 respectively. From these results, it can be seen that, value of resistance obtained using the proposed method is optimum and has a lesser value than that obtained by using conventional method.

When there is more than one DG (multiDG) connected to the system, there should be FCL in series with each DG. In the conventional method, all the FCLs were assumed to have equal resistance. This may result in very high resistance value than what is required, for FCLs placed in certain DG connected buses. But when the proposed method is applied in such a scenario, values of resistance for some of the FCLs can be reduced to a low value, at the same time CTI can be brought above the threshold. With lower FCL resistance, the cost of FCL can be reduced. Thus the proposed

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
1	19	0.130444	0.664403
1	20	-0.634193	0.200024
2	20	-0.267675	0.615085
7	9	0.035201	0.200058

DG connected bus :	10	12
RFCL(pu) :	0.8123	1.8919
ConvFCL(pu) :	3	3

Table 5. Restoration of miscoordinated relay pairs using RFCL for DG at bus 10 and 12

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
1	19	-0.658921	0.200085
1	20	-0.317931	0.943939
2	20	-0.023052	1.35571
3	19	-0.313502	0.515826
6	12	0.135320	0.58153
7	9	-0.867602	0.200215
11	16	0.0143427	0.568862

DG connected bus :	10	19
RFCL(pu) :	2.1129	8.1348
ConvFCL(pu) :	11	11

Table 6. Restoration of miscoordinated relay pairs using RFCL for DG at bus 10 and 19

method is cost effective than the conventional method. Table 5 shows the effect of connecting DGs at buses 10 and 12 simultaneously and the improvement in the CTI value obtained as a result of using the proposed method. There are four miscoordinated backup primary relay pairs. When the proposed method is used, the value of RFCL required to bring the CTI value above the threshold is 0.8123 pu for FCL connected to bus 10 and 1.8919 pu for FCL connected to bus 12. When the conventional method is used, ConvFCL value for both the FCLs is 3 pu. Thus by using the proposed method, FCLs with lower resistance value can be used.

Similarly, Table 6 shows that when DG is connected at bus 10 and 19 simultaneously, the values of RFCL obtained by using the proposed method is 2.1129 pu and 8.1348 pu for FCLs connected to bus 10 and 19 respectively. The ConvFCL value is 11 pu for both the FCLs.

When the DG is connected to bus 12 and 19 simultaneously, Table 7 show that the value of RFCL is 9.8411 pu and 22.8816 pu for FCLs connected to bus 12 and 19 respectively. The ConvFCL value is 19 pu for both the FCLs. The resistance of FCL at bus 19, obtained by the proposed method, is higher than the resistance obtained by conventional method (19 pu). But this increase in resistance value is less compared to the reduction (19 pu to 9.8411 pu) obtained in the proposed method for resistance value of FCL connected to bus 12.

Table 8 shows the scenario when three DGs are connected to the distribution system at bus 10, 12 and 19 simul

Table 7. Restoration of miscoordinated relay pairs using FCL for DG at bus 12 and 19

Primary Relay	Backup Relay	CTI in sec. (with DG and no FCL)	CTI in sec. (proposed method)
1	19	-0.663924	0.201222
1	20	-0.841774	0.564628
2	20	-0.532594	0.97740
3	19	-0.305506	0.52450
4	20	0.131622	1.80290
7	9	-0.479406	0.22317
11	16	0.130907	0.580063

DG connected bus :	10	12	19
RFCL(pu) :	1.5684	5.7910	9.7188
ConvFCL(pu) :	12	12	12

Table 8. Restoration of miscoordinated relay pairs using RFCL for DG at bus 10, 12 and 19

taneously. The number of miscoordinated primary backup relay pairs is seven. When the proposed method is used the values of RFCL are 1.5684 pu, 5.7910 pu and 9.7188 pu for FCL connected to bus 10, 12 and 19 respectively. The conventional method gives a value of 12 pu for all the three FCLs. Thus with the proposed method FCL with lower resistance value can be used for restoring the original relay settings in the presence of DG.

6. Conclusion

This paper introduces an effective method for determining the optimum resistance of resistive FCLs used to restore the original protection scheme of distribution systems in the presence of DG. This approach is applicable for single and multiple DG operation. This method is able to reduce the value of resistance of resistive FCLs by a significant margin when compared to conventional method and thus the cost of FCL can be reduced. There is no need to change the protective devices in the presence of DG, as this method retains the relay coordination without altering the existing relay settings. Genetic Algorithm is used for solving the relay coordination problem and the resistance selection problem.

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Make India a 100% Renewable Energy Nation

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Abstract:

Electricity is an essential ingredient for development. Dependence on depleting energy sources is to be limited to the minimum. Cost of conventional power follows an upward path and cost of solar/wind takes a downward path. Global trend is to reduce conventional power generation by increasing renewable power generation. India's vision is to have 500 GW of solar capacity by 2050. This paper highlights the gravity of situation and the need to go for solar generation to attain energy independence in the long run.

Key words

Historical energy management, evolution of energy management, Solar potential-global & India, coal reserve, global RE growth, JNNSM

I Introduction

We should learn from history that the country that commands a larger share of the world's energy will lead the world. In other words, a country that depends on another country for its energy needs could be subdued. This basic fact should be understood by our nation's planners.

It is recognized without contention that energy is one of the key ingredient required for social, economic and particularly industrial development. The interdependence of energy and industrial sector is of major concern for governments in formulating both energy and industrial policies. The size and structure of the industrial sector determines the amount of investment in the energy sector.

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The abundance of quality power at affordable costs is a necessity for industrial development and for the well-being of citizens. It means power is one of the most important sectors in governance. Government should have real control for inclusive growth. Handing over the power sector to profit (only) motivated entities invite unprecedented rise in tariff, which is sure to arise from the impending shortage of fossil fuel. A powerful legislative mechanism is essential to make the licensee responsible to ensure abundant power at a *reasonable* cost.

The study of energy started with the establishment of civilizations. A civilization is the manifestation of culture. On deeper analysis, it becomes evident that the growth of civilization is in line with the overall management of energy. GDP and civilization has a latent relationship. GDP and energy consumption are closely related. Energy plays a key role in development.

Energy management started with development of primitive tools in the early days of civilization. The aqueduct was a revolutionary concept of the time when developed during the Roman period. It made use of the potential energy of water at a higher level for water to flow downstream. Chengiz Khan, the Mongolian invader could expand his empire using horse regiments. He had great insight and skill in horse breeding and rearing. The backbone of his army was mainly composed of horses. Army could move fast from place to place on horses. The clever king-invader did not march into India fearing a backlash from the Indian army which did consist of horse regiments, elephant regiments and cavalry. Note that these are segments for management of energy. India had, at the time, a superior energy management skill required for army.

Much later we know that the waterwheel revolutionized industrial production. Production centres were established along river banks creating a new industrial culture. Then came the steam engine. It jump started building new production centres where coal or wood were available nearby. After that came diesel engines and electric motors. All these are nothing but activities that involve energy management.

It started with water wheel, steam engine, steam turbine, IC engine, electric motors. No one knows what the next great technology will be for managing energy. The energy for steam engines and diesel engines is from depleting resources. The water wheel disappeared long back and the steam engine is rarely seen. In the next few decades those machines that run on depleting resources will be forced to vanish due to fuel shortage. It is only a matter of time. The process will be accelerated by destructive energy technologies.

II Global scenario

In the current geo-political outlook, the country that uses more energy is considered ‘advanced’ since it has a higher industrial output. I call upon leaders of every political party to engage in nation building by framing a suitable energy policy for generating abundant power from renewable energy sources. Scientists search for viable alternatives to conventional energy. They found that WWS (water, wind and solar) could feed an energy hungry world. Global energy potential is shown in **Figure 1**[1] below. This is the global ground reality.

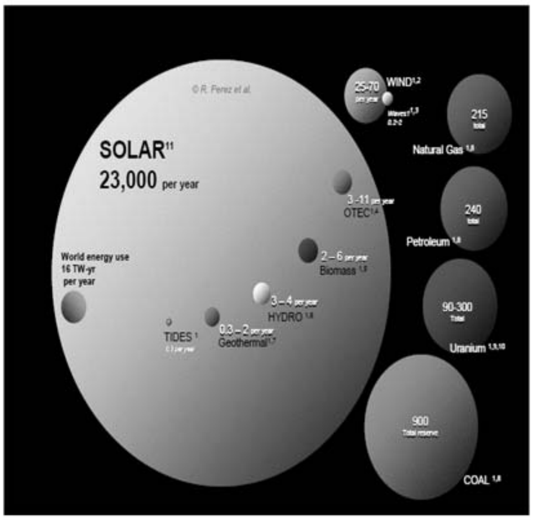


Figure 1: Comparing finite and renewable planetary energy reserves (Terawatt-years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables.

Fig 1 source:www.asrc.albany.

III. Indian scenario

The ground reality in India will not make us happy as reported in the Hindustan Times[2]. “By 2030, India will need three to four times as much energy as we currently use, if our economy is to grow at 8% to 9% a year. We face huge challenges here. We import nearly 80% of our oil consumption - which was 133 metric tonnes (Mt) in 2008-09 and is expected to be around 142 Mt in 2010-11. By 2030, we may need from 350 Mt to 500 Mt of oil a year, depending on our growth rate and the policies we follow. Our domestic production of crude is expected to be around 35 Mt and we will need to import the rest.”

Our coal reserve will not last for too long - a few decades at most. This means India is heading for an energy crisis with unpredictable and unbearable consequences. The mad rush for fossil power should be reviewed and a new era of power generation from renewable sources should be ushered in.

India’s fossil fuel (coal) is depleting fast and will not last beyond 2-3 decades. According to **TERI**[3] **-** “The estimated coal reserve in India is 285.86 billion tons, out of which proved reserve stand at 114 billion tonnes. However, these reserve estimates include a large share that is not extractable due to technical reasons or because it falls under forest land, among other reasons. Recent estimates now place extractable reserves at 21.8 Billion tonnes (2011), which are expected to last 35-40 years at current rate of exploitation. India also has lignite reserves of 39.9 Billion tonnes (MOSPI 2012)”. This projection is to be viewed with all its seriousness. India has to find ways to meet rising electricity demand from renewable sources. Oil/gas has passed ‘peak-in’ globally in 2012. An acute shortage of fossil fuel can be expected in a few decades if not in a few years. This would lead to unprecedented rise in cost of grid power. Extent of rise has to be ascertained through detailed study.

IV. Roadmap

Switching over to renewables cannot be accomplished overnight. It requires meticulous planning and execution over a long period of time. We need a conversation between professionals in every discipline to join hands to evolve mechanisms that will accelerate renewable generation and reduce gradually power generation from fossil fuel sources.

Around the world, industrialized nations aim to become 100% renewable energy states. They realised the truth that renewable sources alone will provide energy in abundance for indefinite period of time.

India’s efforts for enhanced generation from renewable sources does not match the projected target. India has a vision to have 200 GW solar installed capacity by 2050 but could add just 2 + GW in three years through JNNSM. It is time to rethink the policy framework. Seems JNNSM needs a restructuring. We have no time to do a trial and error method to finalise the policy. We should learn successful stories from around the world and frame policies with modifications. Now that the government has revised the target to 100 GW by 2022 and 500 GW by 2050 the policy should aim the new target.

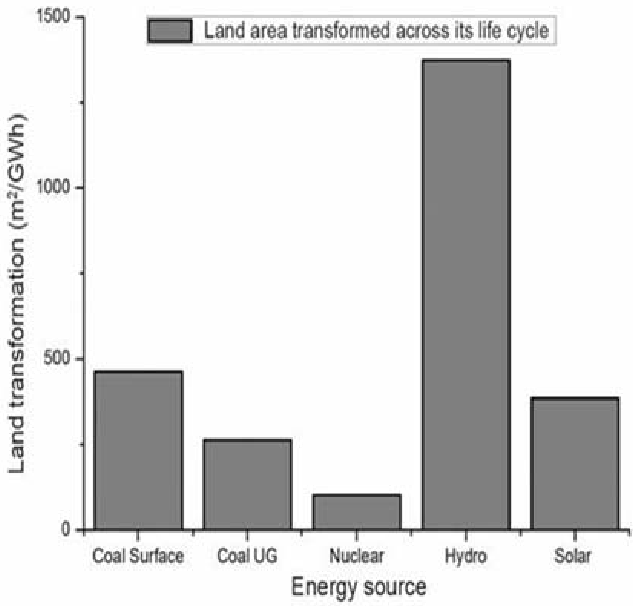
Considering the stupendous potential, the solar sector is bound for tremendous growth in the coming decades. India’s solar potential is not estimated yet. “The roof-top solar power technology, along with that proposed by IISc professors, (H. Mitavachan and J. Srinivasan) will be able to meet most of the electricity demand, and has the potential to transform the power sector," says Shankar Sarma, a power policy analyst in his **book**[4] - 'Integrated Power Policy'

According to a **report**[5] 4.1 per cent of the total uncultivable and waste land area in India is enough to meet the projected annual demand of 3,400 terawatt-hour (TWh) by 2070 from solar energy alone. A comparative study of land requirement for generating plants for different sources is shown in Fig 2

Fig 2 *source: http://www.l-a-k-e.org/blog*

Solar sector is going to be a thriving field with huge investments. One GW requires an investment of 6000 crores at the present estimate. With proper planning we can accomplish energy independence in fifty years. No more import of oil/gas. One MW of solar installed capacity saves 3-4 crores rupees per year in import of crude oil!

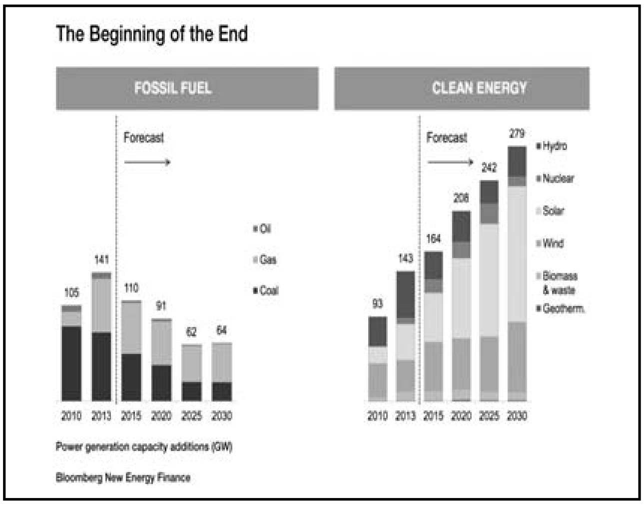
India could conserve its huge coal reserve (10% of global reserve) for future by switching over power generation from renewable sources. India needs coal for purposes other than power generation. Availability of coal for other purposes can thus be extended for a few more centuries.



European Union changed their approach in building new power projects. 80% of generation capacity additions in European Union for the last three years (average) is from renewable sources.

Here is the global projection of capacity addition. **Fig 3**[6]

Fig 3



This is a pointer for our planners. We can learn from Japan. Japan was quick to redraft their renewable energy policy within a year after the Fukushima disaster, jump starting a steep rise in solar generation from 6 GW in 2012 and is expected to accomplish 37 GW and 79 GW installed capacity by 2020 and 2030. Global cumulative target is 422 GW by 2017 from 140 GW in 2013. India can frame a policy aiming to accomplish our target of 500 GW by 2050 taking into account the Indian condition. Time is running out.

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A Proposal for Reliability Enhancement of Distribution System

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Abstract

Reliability indices viz. System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Average Service Availability Index (ASAI) etc. are measures of system reliability. These indices also indirectly indicate the utility's Operations and Maintenance (O&M) efficiency, system's ability to transfer load to the neighbouring units in case of equipment failures, response time to locate and isolate a fault and restoration time. In this paper a detailed description is given for improving the reliability of the distribution utility. The improvement in reliability by suitable interventions is ascertained by the improvement in reliability indices. An attempt is made for identifying the distribution automation (DA) components for improving reliability indices; placement of DA components; operation of DA components and computation of reliability indices after the introduction of DA components etc. have been carried out in this work. Case studies are presented to bring out the usefulness of the proposed approach.

Keywords: Reliability Indices, Distribution Automation, DA Components.

I. INTRODUCTION

The reliability of the distribution system is important for providing uninterrupted and quality power supply for consumers. The evaluation of reliability is important for utilities as they try to provide supply with optimal reliability and quality within economic constraints. A fault in one or more components of the distribution network can affect reliability and quality. A failure even in one network component can interrupt power to a large number of consumers. The duration of this outage will depend on speed of the process of restoring supply from an alternate source. If the faulty part can be isolated and supply restored by the system itself, the outage duration will be shorter. The reliability of distribution networks is dependent on frequency of faults and their duration [1].

This paper presents the reliability studies on one sub-station and one distribution automation project centre in the state of Kerala, India. The system indices such as SAIFI and SAIDI are computed for a real radial distribution system. This paper also investigates the improvement in reliability indices by employing automation in the distribution network.

1.1. RELIABILITY INDICES

System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Average Service Availability Index (ASAI) etc are known as relibilty indices of an electrical energy distribution system. These are measures of system reliability of an electricity distribution utility [1]. These indices also indirectly indicate the utility's Operations and Maintenance (O&M) efficiency, system's ability to transfer load to the neighbouring units in case of cable or equipment failures, response time to locate and isolate a fault and restoration time, quality of the power supply etc. The indices can be calculated as follows

1.1.1 System Average Interruption Frequency Index:

The system average interruption frequency index indicates how many sustained interruptions the average customer experiences over a predefined period of time, usually taken to be one year.

$$\text{SAIFI} = \frac{\sum \text{Total number of Customers Interrupted}}{\text{Total number of Customers Served}}$$

1.1.2 System Average Interruption Duration Index:

The system Average Interruption Duration Index (SAIDI) is an indicator of how many interruption hours (or minutes) an average customer will experience during a predefined period of time, usually one year.

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total number of Customers Served}}$$

Ideal value of SAIFI and SAIDI are zero. Large value of SAIFI and SAIDI give indication of poor performance of the utility and the distance from the ideal value should be minimized.

1.2 OBJECTIVE OF THE PAPER

The objective of this paper is to propose a method for improving the reliability of an electrical sub-station by employing Distribution Automation System (DAS). This is to achieve increased simplicity in 11 KV network operation & control, faster fault location, isolation and service restoration. It also calls for supply reliability improvement, reduction of losses in the system and improved voltage profile due to feeder rearrangement.Improvement in quality of service, equipment availability, manpower saving in operation and maintenance can be achieved. In order to use technology advancement in network management and to have better tools for short term and long term distribution planning.

ORGANISATION OF THE PAPER

Section 2 gives the real system data of the sub-station , Mavelikkara. Section 3 gives the reliability indices calculation of the sub-station. A detailed discussion of the result and proposal for reliability improvement is given in section 4 and in section 5 the conclusion of the paper is given.

2. SYSTEM DETAILS

The 110 kV sub-station at Mavelikkara consists of two numbers of 40 mVA, 110 kV/66 kV transformers, three numbers of 10 MVA, 66 kV/ 11kV transformers. Two numbers of 110 kV incoming feeders, seven numbers of 66 kV feeders running to 66 kV sub-stations, three numbers of 11 kV incomers, eight numbers of 11 kV outgoing feeders and one 11 kV auxiliary feeder for station supply. This area has approximately 40,000 consumers served through overhead distribution feeders. The consumers is mostly residential and small commercial, the feeders are radial and mostly overhead. Given the characteristics of the customers and their sensitivity to interruptions, the main goal pursued in this paper was achieving SAIDI (reducing customer interruption duration).

3. CALCULATION OF RELIABILITY INDICES

As a first step, one year interruption data is collected from 110 kV sub-station Mavelikara. Reliability Indices SAIFI and SAIDI are calculated from the interruption data under the present operating condition. Table 3.1 shows the one year interruption data for the period August-2011 - July-2012. Table 3.1 tabulates the one year interruption data for the period between August-2011 and July-2012. Table 3.2 shows the reliability indices SAIFI and SAIDI of 11 kV incoming and outgoing feeders for scheduled and un-scheduled interruptions between Aug 2011and Jul 2012. The unscheduled interruptions are the interruptions of the power supply due to the 11 kV feeder fault as a result of Earth Fault and Over Current Fault (Symmetrical and un symmetrical line to line fault).The scheduled interruption includes the momentary switch offs (Known as ‘Blink’) given to the feeder managers to isolate a portion of the line by opening an Air Break Switch or to put a portion of feeder back to service by closing the AB switch after clearing a fault condition or Maintenance. This also includes the ‘Permit to Work’ issued to the feeder manages on request to carry out a maintenance work, which can be a pre planned or contingency maintenances

Name of feeder	Number of scheduled Interruption	Duration of scheduled Interruption(s)	Number of unscheduled Interruption	Duration of un-scheduled Interruption(s)	Number of interruption/ duration(min)
11 kV Incomer no:1	21	2161	2	64	23/37.082
11 kV Incomer no:2	20	2646	2	8	22/44.233
11 kV Incomer no:3	28	9449	8	136	36/159.746
11 kV Olakety	572	7573	208	2393	780/166.099
11 kV Chenganoor	537	7069	242	3601	779/177.832
11 kV Pathiyoor	479	9115	273	4297	752/223.53
11 kV Kayamkulam	544	6500	207	2051	751/142.513
11 kV Mannar	574	9280	305	4456	879/228.932
11 kV Thatarambalam	474	8762	240	3079	714/197.349
11 kV Mavelikara	516	7616	869	2977	785/176.549
11 kV Chennithala	541	6816	301	2424	842/154

Table 3.1 The one year interruption data for the period between August-2011 and July-2012 of 110 kV Substation, Mavelikara

Name of feeder	Total no: of consumers	Number of interruption/ duration(min)	SAIFI	SAIDI
Incomer no:1	9250	23/37.082	0.00238	0.0040089
Incomer no:2	14000	22/44.233	0.00157	0.0031595
Incomer no:3	13700	36/159.746	0.00263	0.0116602
11 kV Olakety	3950	780/166.099	0.19746	0.0420504
11 kV Chenganoor	4750	779/177.832	0.16400	0.0374383
11 kV Pathiyoor	5000	752/223.532	0.1504	0.0447064
11 kV Kayamkulam	4000	751/142.513	0.18775	0.0356283
11 kV Mannar	4500	879/228.932	0.19533	0.0508738
11 kV Thatarambalam	5500	714/197.349	0.12982	0.0358816
11 kV Mavelikara	4500	785/176.549	0.17444	0.0392331
11 kV Chennithala	4750	842/154	0.17726	0.0324211

Table 3.2 SAIFI and SAIDI of 11 kV incoming and outgoing feeders for scheduled and un-scheduled Interruptions (Aug 2011-Jul 2012)

4. RESULTS AND DISCUSSION

The average time for fault detection, isolation and restoration without Distribution Automation system is assumed to be 30 minute and from the above data the total number of consumers per feeder is 5000. From the above data SAIDI = 30/5000 = 0.006. The average time for fault detection, isolation and restoration with DA is 3 minute and the corresponding SAIDI = 03/5000 = 0.0006. So from this we obtained the improvement in SAIDI = ((0.006 – 0.0006) / 0.006) *100 = 90%. With Full Loop scheme, mid-circuit re-closers & RMU, SAIFI can be improved by 50%

4.1 PROPOSED DISTRIBUTION AUTOMATION SYSTEM

Loop distribution system is the most widely used distribution configuration of any modern system [2]. Figure 4.1 shows the proposed full loop scheme feeding from both ends with mid-circuit re-closers and Ring Main Unit (RMU).

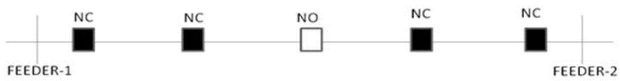

Fig: 4.1 Full loop schemes with reclosers

Name of feeder	Number of customers	Number of interruption/ duration(min)	SAIFI	SAIDI	New SAIFI	New SAIDI
Incomer no:1	9250	23/37.082	0.00238	0.0040089	0.001189	0.00040089
Incomer no:2	14000	22/44.233	0.00157	0.0031595	0.000785	0.00031595
Incomer no:3	13700	36/159.746	0.00263	0.0116602	0.001314	0.00116602
Olakety	3950	780/166.099	0.19746	0.0420504	0.09873	0.00420504
Chenganoor	4750	779/177.832	0.164	0.0374383	0.082	0.00374383
Pathiyoor	5000	752/223.532	0.1504	0.0447064	0.0752	0.00447064
Kayamkulam	4000	751/142.513	0.18775	0.0356283	0.093875	0.00356283
Mannar	4500	879/228.932	0.19533	0.0508738	0.097665	0.00508738
Thatarambalam	5500	714/197.349	0.12982	0.0358816	0.064909	0.00358816
Mavelikara	4500	785/176.549	0.17444	0.0392331	0.087222	0.00392331
Chennithala	4750	842/154	0.17726	0.0324211	0.088631	0.00324211

Table 4.1 Improvement in SAIFI and SAIDI of 11 kV incoming and outgoing feeders by Distribution Automation

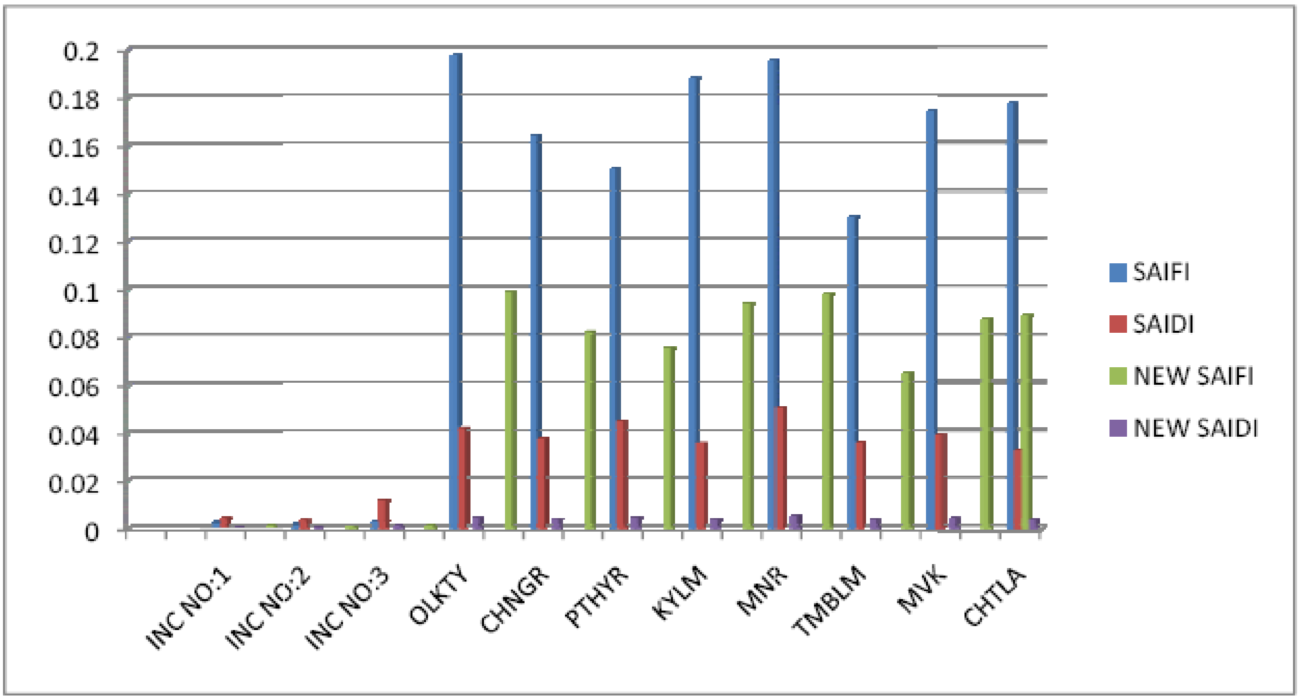

Fig. 4.2 The histogram showing the improvement in SAIFI and SAIDI of 11 kV incoming and outgoing feeders by Distribution Automation.

In this study the reliability is calculated for an automated sub-station and the reliability indices obtained have wide variation from the actual value. This is because after a feeder is declared faulty , the utility engineers has to isolate the faulty feeder by opening Air-Break switch and charge the healthy portion from the sub-station. Depending on the fault location and nature of fault, restoration time may vary from sever minutes to hours .The interruption data taken from the sub-station does not give the actual duration of fault and the actual number of consumers affected by the fault.

If the interruption data of the feeders at various locations is made available, then the reliability of the distribution system can be improved considerably by employing the proposed distribution automation system.

5. CONCLUSION

This paper has presented the methodology and procedures used for improving the reliability of a distribution system. The reliability indices SAIFI and SAIDI are calculated using one year interruption data of a real utility under the normal operating condition. The improvement in reliability indices SAIFI and SAIDI are calculated by introducing distribution automation. The different feeder reliability improvement options that were studied include the implementation of mid – circuit and trip saver re-closers, full and half loop schemes. These indices were then improved by employing distribution automation.

6. ACKNOWLEDGEMENT

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Analysis and Comparison of Dynamic Performance of Various PLLs used in Distributed Generation Systems

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Abstract - **The need for new Control Strategies for interconnecting the Renewable energy system has become an important aspect in the DGS (Distributed Generation Systems). For the control structure to be effective, fast tracking of the phase is required. Thus different kinds of Phase Locked Loop Techniques have come into existence. In this paper, four different kinds of Phase locked loops (PLLs) Synchronous reference frame PLL (SRF), Stationary reference frame PLL (AB PLL), Decoupled Synchronous Frame PLL (DSRF PLL), Decoupled Stationary frame PLL (DAB PLL) are analyzed. The first two PLLs are conventional PLLs and the DSRF and DAB PLLs have decoupling and form a solution for interconnecting the DGS with Fault Ride Through (FRT) Capability. The operation of each PLL is clearly explained and the advantages and disadvantages are discussed. The PLLs are simulated under normal and faulty conditions using MATLAB/Simulink and the results are enumerated.**

Keywords— **PLL, decoupling, three phase fault, grid interfacing**

I. Introduction

The use of fossil fuels in power generation has put several problems on the environment including the green house effect. This has laid a path for the Distributed Generation Systems (DGS) where the renewable energy sources such as wind power, hydro power, solar power, fuel cells are into it [1],[2]. These renewable energy sources utilize power electronic converters for grid integration. Mainly, the grid side converter is responsible for the injection of sinusoidal quantities into the grid [3]. The key element to maintain the voltage at the Point of common coupling (PCC) is the grid side converter. Grid stability, synchronization, power quality constraints, fault ride through and power flow can be controlled by the grid side Converter. The major issue is the synchronization of utility voltage vector with that of the grid [4] .For this, the phase angle of the utility voltage must be tracked to control the flow of the real and reactive powers. Effective controllers must be used for the grid side converter to ensure the safe and reliable operation of the Distributed Generation Systems (DGS).

Generally, Synchronous PI (proportional Integral) controllers and PR (Proportional Resonant) controllers are used in the control system of the grid side converters. When the Synchronous PI controllers are used, the most important element in synchronizing with the utility is the phase angle of the utility voltage vector at the point of common coupling. For this purpose, phase tracking algorithm called Phase locked loops (PLL) is used [5]. When using the Proportional Resonant controllers, the frequency of the utility would be the key element. So the Frequency Locked Loop (FLL) algorithm is used [6], [7].

In this paper, four different Phase locked loop algorithms are explained. They are

1) Synchronous reference frame PLL (SRF PLL)

2) Stationary reference frame PLL (AB PLL)

3) Decoupled Synchronous reference frame PLL (DSRF PLL)

4) Decoupled stationary reference frame PLL (DAB PLL)

The operation of the above mentioned techniques including the advantages and disadvantages are explained in the following sections. The simulations of all the PLLs are done using MATLAB/Simulink and are tested under normal and faulty conditions.

II. Basic Principle of a PLL

Various grid synchronization algorithms are proposed in the literature. One of them is the Zero crossing detector (ZCD) [5]. This circuit detects the transition of the voltage from positive to negative and generates a pulse at every transition.

The disadvantage of the zero crossing detectors (ZCD) is it is badly affected by the power quality phenomena.

A PLL synchronizes its output signal with a given reference signal both in frequency and phase. It is a non-linear closed loop control which automatically matches the frequency and phase of the output signal with that of the reference signal. The main components of a PLL are a phase detector which compares the phase of the input and output signal and generates an error, a loop filter which filters out the unwanted harmonics, a voltage controlled oscillator (VCO) which produces the phase that is matched to the reference signal. The Block diagram of a PLL is shown in Fig 1.

I11. Types of PLLs

In this section, different PLL Algorithms are studied.

A. Synchronous Reference Frame PLL (SRF PLL)

The basic configuration is shown in the figure below. The SRF PLL [8] uses the equations of the Park's transformation,

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix}^{syn} = \frac{2}{3}\begin{bmatrix} cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ -sin\theta & -\sin(\theta-120) & -\sin(\theta+120) \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

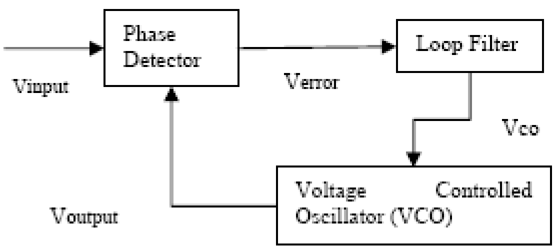


Fig. 1 Structure of a Phase Locked Loop.

as shown below, to translate the abc natural rotating reference frame into the dq-synchronous reference frame (SRF).

In this PLL either direct axis component or quadrature axis component of voltage can be considered for the estimation of frequency or hence phase angle. A crucial aspect of the transformation is that the voltage of the d-axis (V_d) has to lie on the voltage of phase a. This is achieved by having the voltage of the q-axis (V_q) to track zero through a proportional-integral (PI) controller and therefore frequency, ù $_{srf}$ and phase, è $_{srf}$ could be estimated as illustrated in Fig. 2. In this PLL, the PI controller performs the function of Loop filter in the basic PLL. The angle è $_{srf}$ is found integrating the output ù $_{dqPLL}$ which uses the error signal V_q-V_q^{ref} in the dq frame.

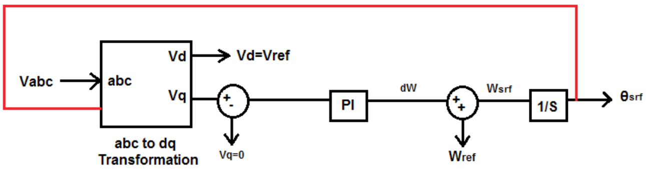


Fig. 2 The structure of a SRF PLL.

When a balanced fault occurs, the SRF PLL is operating well and can track the phase angle. However, when an unbalanced fault occurs, then the SRF PLL fails to track accurately the phase angle because V_d does not perfectly match with the positive sequence voltage V_{+1} due to the oscillation which appears because of the existence of the negative sequence voltage V_{-1} under unbalanced disturbances.

A. Stationary Reference Frame PLL (AB PLL)

The basic configuration of a Stationary reference frame PLL [9]-[11] is shown in Fig 3. The ABPLL sets *è=0* in that of SRF PLL, in order to translate the abc natural rotating reference frame into the á â-stationary reference frame. Trigonometric equations are used in order to estimate the phase angle *è* $_{AB}$ as shown below. It should be noticed that the below expression is valid if *Äè* is small.

$$\Delta\theta = \theta_\theta - \theta_{\alpha\beta} \approx \sin(\theta_\theta - \theta_{\alpha\beta})$$
$$\Leftrightarrow \Delta\theta \approx \sin(\theta_\theta)\cos(\theta_{\alpha\beta}) - \cos(\theta_\theta)\sin(\theta_{\alpha\beta}) \quad (2)$$

The objective of the closed loop control of AB PLL (Fig. 3) is to induce the difference *Äè* to be controlled to zero by using a PI controller, where *è* $_{gr}$ is the actual phase angle of the voltage.

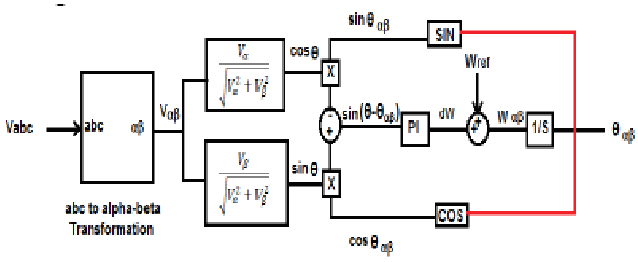


Fig. 3 The structure of AB PLL

The ABPLL in unbalanced operation has similar problems to those mentioned for the SRF PLL.

C. Decoupled Synchronous Reference Frame PLL (DSRF PLL)

The DSRF-PLL [12] stems from improving the conventional SRF-PLL. It consists of a decoupling network and phase locked loop operating on synchronous reference frame (SRF-PLL). The decoupling network provides positive and negative sequence components from the input voltage vector. The synchronization to the positive sequence component of the grid voltage is achieved when the voltage positive sequence q-component is controlled to zero. This is done using SRF-PLL.

When the three phase grid voltage is unbalanced, the fundamental positive-sequence voltage vector appears as a DC voltage on the dq^{+1} axes of the positive sequence SRF and as ac voltages at twice the fundamental utility frequency on the negative sequence voltage vector will cause a dc component on the negative sequence SRF and an ac oscillation on the positive sequence SRF. Since the amplitude of the oscillation on the positive sequence SRF matches to the DC level on the negative sequence SRF and vice versa, a decoupling network is applied to signals on the dq positive/negative SRF axes in order to cancel out such ac oscillations. Low pass filters are in charge of extracting DC component from the signal on the decoupled SRF axes. These DC components collect the information about the amplitude and phase angle of the positive and negative sequence components of the grid voltage vector.

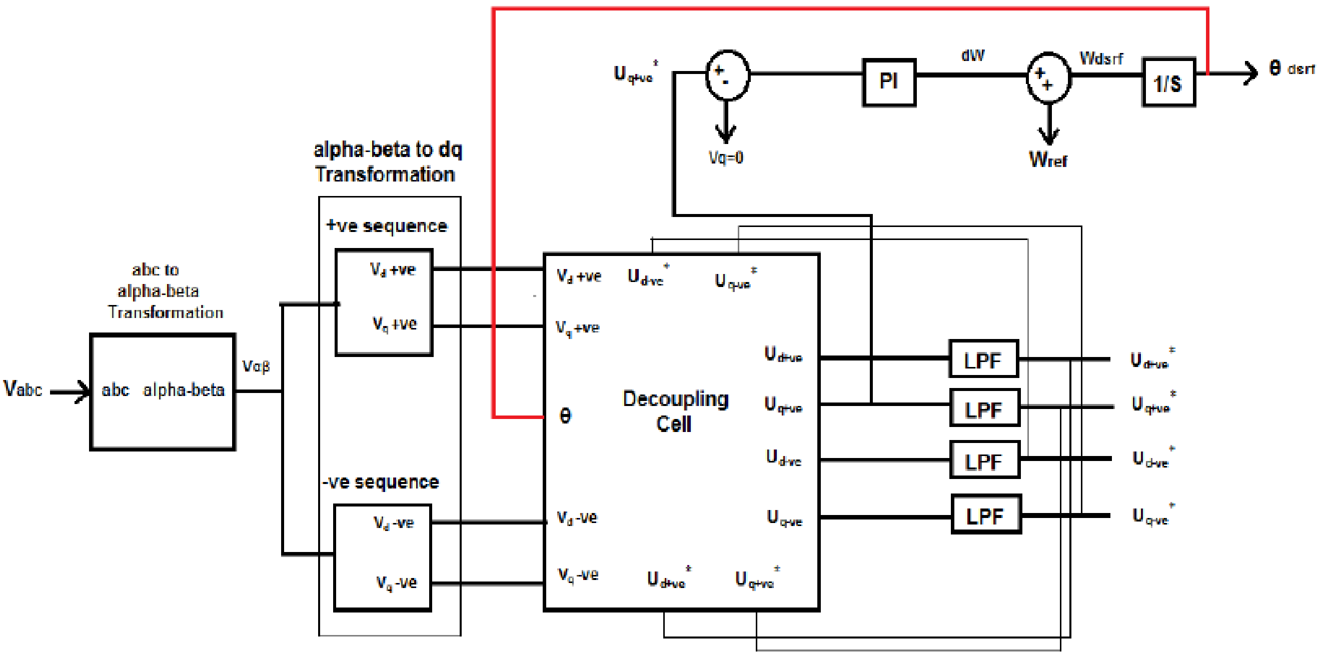


Fig. 5 The structure of DSRF PLL

The loop controller of the DDSRF-PLL works on the decoupled q-axis signal of the positive sequence SRF (U_q^{+1}). The signal is free of ac components due to the effect of the decoupling cells and the band width of the loop controller can be consequently increased.

Decoupling Network: The unbalanced grid voltage vector $u_{áâ}$ can be expressed in stationary reference frame as follows

$$V_{\alpha\beta} = \begin{matrix} V_\alpha \\ V_\beta \end{matrix} = V^+ \begin{matrix} \cos(\omega t + \varphi^+) \\ \sin(\omega t + \varphi^+) \end{matrix} + V^- \begin{matrix} \cos(-\omega t + \varphi^-) \\ \sin(-\omega t + \varphi^-) \end{matrix}$$

(3)

Where V is peak value of the phase voltage, *ù* is angular frequency of the grid and ö is initial angle. Superscripts + and - correspond to the positive and negative sequence references. It is assumed that the positive sequence reference frame is rotating synchronously with the fundamental frequency positive sequence grid voltage component. Thus, $è_{sync}$ = ù*t*.

The positive and negative sequence components can be expressed in synchronous dq reference frame using angle $è_{sync}$ which is the output of the SRF-PLL.

$$U_{dq}^{+} = \begin{bmatrix}U_d^+\\ U_q^+\end{bmatrix} = [T_{dq}^+]\begin{bmatrix}V_\alpha\\ V_\beta\end{bmatrix} = \begin{bmatrix}\cos(\theta_{sync}) & \sin(\theta_{sync})\\ -\sin(\theta_{sync}) & \cos(\theta_{sync})\end{bmatrix}\begin{bmatrix}V_\alpha\\ V_\beta\end{bmatrix}$$

$$= V^+\begin{bmatrix}\cos(\varphi^+)\\ \sin(\varphi^+)\end{bmatrix} + V^-\cos(\varphi^-)\begin{bmatrix}\cos(2\omega t)\\ -\sin(2\omega t)\end{bmatrix} + V^-\sin(\varphi^-)\begin{bmatrix}\sin(2\omega t)\\ \cos(2\omega t)\end{bmatrix} \quad (4)$$

$$U_{dq}^{-} = \begin{bmatrix}U_d^-\\ U_q^-\end{bmatrix} = [T_{dq}^-]\begin{bmatrix}U_\alpha\\ U_\beta\end{bmatrix} = V^-\begin{bmatrix}\cos(\varphi^-)\\ \sin(\varphi^-)\end{bmatrix} + V^+\cos(\varphi^+)\begin{bmatrix}\cos(2\omega t)\\ \sin(2\omega t)\end{bmatrix} + V^+\sin(\varphi^+)\begin{bmatrix}-\sin(2\omega t)\\ \cos(2\omega t)\end{bmatrix} \quad (5)$$

The left side terms in the above equations are DC-values and right side terms are AC-values. The DC-values are solved in order to distinguish the positive and the negative sequence components from the grid voltage.

$$V^+\begin{bmatrix}\cos(\varphi^+)\\ \sin(\varphi^+)\end{bmatrix} = \begin{bmatrix}V_d^+\\ V_q^+\end{bmatrix} = \begin{bmatrix}U_d^+\\ U_q^+\end{bmatrix} - V^-\cos(\varphi^-)\begin{bmatrix}\cos(2\omega t)\\ -\sin(2\omega t)\end{bmatrix} - V^-\sin(\varphi^-)\begin{bmatrix}\sin(2\omega t)\\ \cos(2\omega t)\end{bmatrix} \quad (6)$$

$$V^-\begin{bmatrix}\cos(\varphi^-)\\ \sin(\varphi^-)\end{bmatrix} = \begin{bmatrix}V_d^-\\ V_q^-\end{bmatrix} = \begin{bmatrix}U_d^-\\ U_q^-\end{bmatrix} - V^+\cos(\varphi^+)\begin{bmatrix}\cos(2\omega t)\\ \sin(2\omega t)\end{bmatrix} - V\sin(\varphi^+)\begin{bmatrix}-\sin(2\omega t)\\ \cos(2\omega t)\end{bmatrix} \quad (7)$$

The decoupling network based on (6) and (7) is used to cancel AC components from positive and negative sequence reference frames. The block LPF represents a simple first order low-pass filter with cut-off frequency of ù$_f$

$$LPF(s) = \frac{\omega_f}{s+\omega_f} \quad (8)$$

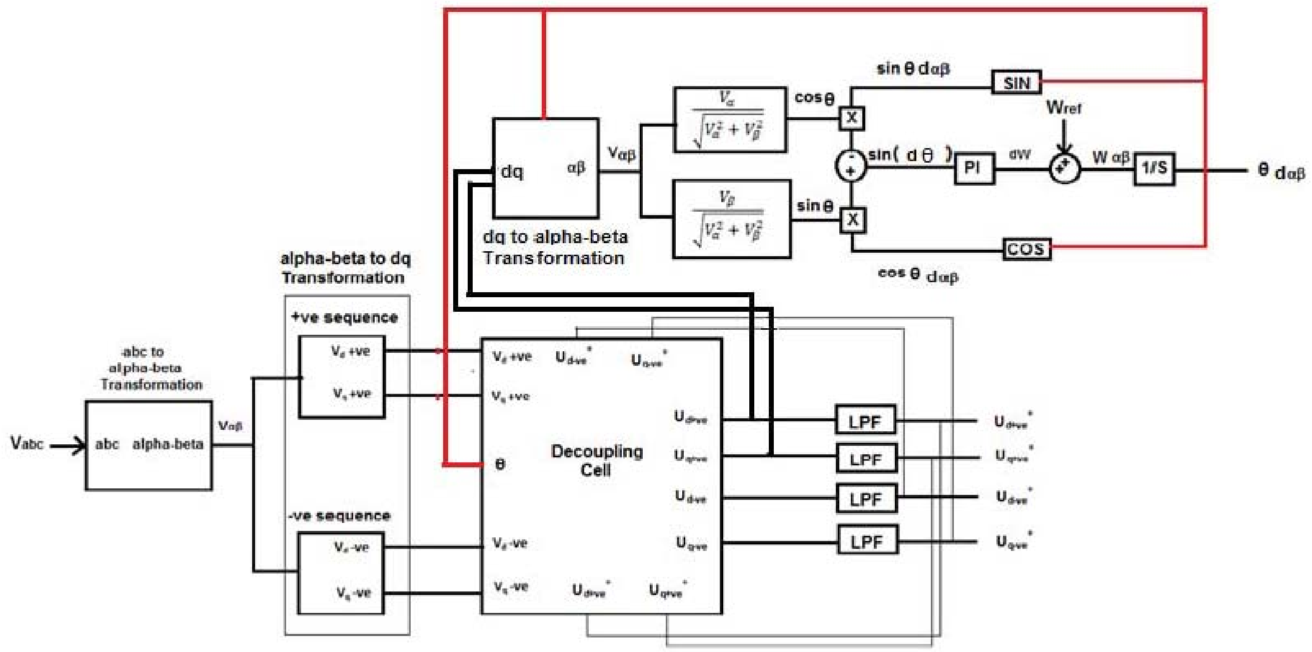


Fig. 6 The structure of DAB PLL

The decoupling network provides positive and negative sequence components from the input voltage vector. Thus, it is possible to synchronize the control system of the GSC to the grid voltage positive sequence component. The synchronization to the positive sequence component of the grid voltage is achieved when the positive sequence q axis voltage component U_q^{+} is zero. In that case, the initial phase angle ö$^+$ is zero and the positive sequence voltage component is aligned to d^+ axis rotating with angular speed of ù . The angle of positive sequence voltage component è$_{sync}$ is obtained using SRF-PLL.

The discrete controller and the integrator can be built using a backward numerical approximation. The frequency and phase can be then represented in the z-domain as shown in the equation considering U_q^{+1} as the error to be minimized. In this equation a feedforward of the nominal frequency is given by means of ù$_{nom.}$.

$$W(Z) = \frac{(Kp+Ki.Ts)z-Kp}{z-1} \,.\, Uq^{+1}(Z) + \omega_{nom}.$$

$$\theta^{+'} = \frac{Ts.z}{z-1} \,.\, W'(Z) \qquad (9)$$

A sample representation delivers finally, equations which are the expressions to be programmed. In these equations a frequency feedforward has been included by introducing a initial condition to W'.

$$W'[n+1] = W'[n] + (Kp + Ki.Ts).U_q^{+1}[n+1]$$

$$\theta^{+'}[n+1] = \theta^{+'}[n] + Ts.W'[n+1] \qquad (10)$$

Although in terms of code complexity, the DDSRF PLL is more complex than SRF PLL, due to its excellent performance under unbalanced conditions of the network, the former is preferred for industrial applications. When the bandwidth is reduced, the PLL performance is good even under distorted conditions.

The only drawback of the DDSRF PLL is the high overshoot in the phase angle and frequency estimation, which appears at the instant the fault, occurs.

A. Decoupled Stationary Reference Frame PLL (DAB PLL)

This PLL is developed by the study of the results of all the above mentioned PLLs. The change in the time response of each PLL results in the overshoot problems which are highly undesirable and results in power quality problems. With the fast operation of the PLLs the peak overshoot problems increase. Among the three PLLs explained above, the AB PLL has the less peak overshoot.

So the same decoupling concept that is observed in the case of DSRF PLL is applied to the AB PLL.

The DAB PLL aims at operating very accurately under balanced and unbalanced disturbances and also at having a lower phase angle and frequency overshoot than the DSRF PLL. Therefore, the desired faster operation could be achieved by the suggested DAB PLL within the same

frequency limits. The structure of the proposed DAB PLL is illustrated in Fig 5.

IV. Simulation Results

The four PLLs are tested under normal and three phase balanced and unbalanced faulty conditions.

A. Performance of DAB PLL under normal grid conditions

The DAB PLL is simulated for a grid voltage of 415 volts and 50Hz frequency. The results are shown below.

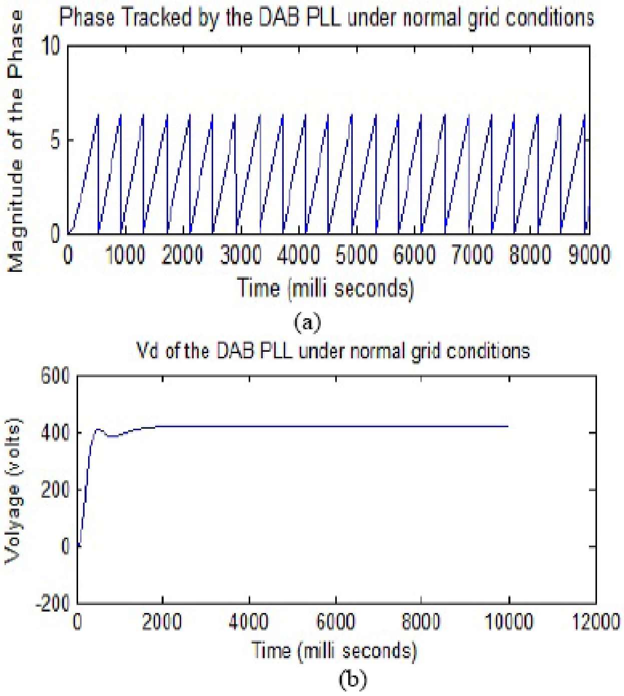
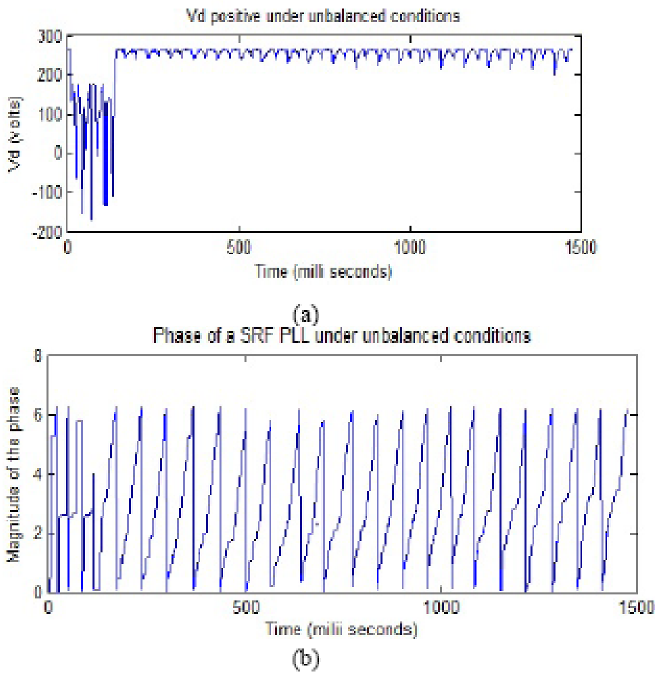


Fig.6 (a) The phase tracked by the DAB PLL (b) The positive voltage component of the DAB PLL

B. Performance of each PLL under faulty grid conditions

A three phase fault is applied to all the four PLLs and their results are shown below. The unbalanced type fault is applied i.e, only the phases a and b are faulty where as phase c is in normal condition.



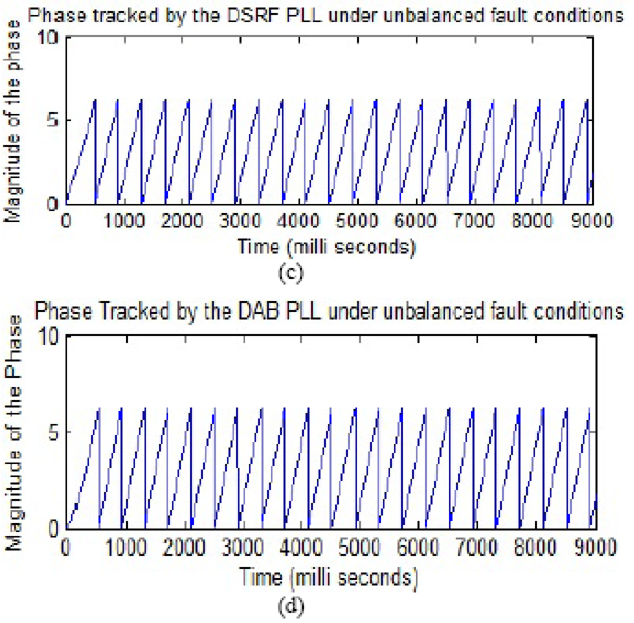
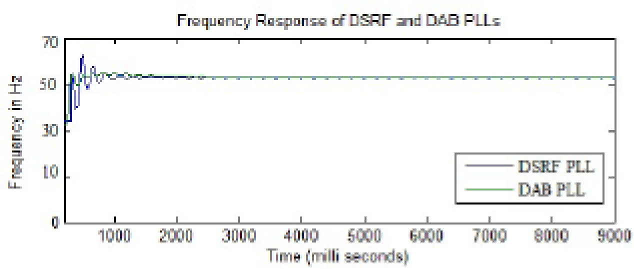


Fig.7 (a) The voltage V_d of the DSRF PLL (b) The phase tracked by SRF PLL (c) DSRF PLL(d) DAB PLL under unbalanced grid conditions.

C. *Frequency Response of DSRF and DAB PLLs*

The DSRF and DAB PLLs are effective in tracking the phase angle quickly and accurately when connected to the DGS. The Frequency response of both the PLLs is compared under non ideal grid conditions i.e, under two phase unbalanced conditions. It is observed that the peak overshoot of the DSRF PLL is high when compared to that of the DAB PLL. Almost 29% of higher overshoot is noticed in DSRF PLL. The Frequency Response of these two PLLs is shown below in Fig. 8.The Frequencies of the two PLLs under unbalanced grid conditions is obtained as 50Hz but the settling time and the peak overshoot of the two PLLs are different. This becomes a serious problem when interconnected to DGS. So the DAB PLL is an appropriate solution for tracking the phase when the GSC is connected to the grid.



.8 Frequency Response of DSRF and DAB PLLs.

V. Conclusion and Future Work

A benchmarking study of the effect of the time response on the overshoot of the estimated frequency and phase angle for the DSRF and DAB PLLs is performed in this paper. The investigation of SRFPLL, ABPLL and DSRF PLL motivates the proposal for a new PLL, which inherits the advantages of each PLL. The DAB PLL is the most beneficial solution for grid synchronization compared to the other three PLLs under investigation, since it operates accurately under balanced and unbalanced conditions and also reduces the overshoot on the estimation of the phase angle and frequency, which is the main drawback of DSRF PLL. The lower frequency overshoot of DABPLL leads to a faster time response without any violation of the frequency limits of the grid codes.

The proposed DAB PLL could be very useful in synchronizing the inverter to the grid. The modelling and control of utility interactive inverters can be done more efficiently using the State of the art techniques that are available for Grid synchronization, anti-islanding control and current regulation. Control algorithms can be given in digital control format applicable to embedded control using digital signal processors.

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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.

Optimal Operation of Pumped Storage Hydroelectric Power Plant

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Abstract— **In the vertically integrated systems, hydrothermal coordination is used to reduce the fuel cost and emission by letting the pumped-storage generators serve the peak load and then pumping the water back into the upper reservoir at light load periods. In a competitive electricity market, independent pumped-storage unit owner can now buy and sell electricity either in the day-ahead and real-time markets or with bilateral contracts. Distributions of day-ahead hourly market clearing price (MCP) of a typical electricity market show a significant price margin between the on- and off-peak periods. During the off-peak period, purchase of electricity for pumping reduces the procurement cost. During the on-peak period, the MCP is relatively higher; therefore, pumped-storage plant can generate and sell the electricity. The profit of the pumped-storage plant may be increased so that the generating periods occur at price peaks and the pumping periods occur at price valleys.**

The income of a pumped-storage unit includes the revenue received by trading in the energy market and by being accepted in the non-synchronous reserve market when it is offline. The pumped-storage unit can also be committed for synchronous reserve market when it is in the pumping mode, because it can readily reduce its pumping power and, consequently, reduce the overall system load. Thus, there are strong incentives for pumped-storage power plants to optimize their self-scheduling in the multiservice electricity markets. Simulation results for different operating cycles of the storage plant indicate the attractive properties of this approach with highly optimal solution and robust convergence behavior

Index Terms— **Pumped-storage, bidding strategy, day-ahead market, self-scheduling.**

I. INTRODUCTION

Managing the balance between energy production and consumption levels has become an issue of growing importance in order to guarantee the stability of electrical networks. Pumped storage hydroelectricity is the only economic and flexible means of storing large amounts of excess energy, allowing power plants to successfully manage that balancing act. This is becoming even more important as more and more countries are increasing their nuclear power generation capacities and ramping up their power generation from renewable such Wind and Solar that are not intermittent.

In pumped storage plants, Pump turbines transfer water to an upper storage reservoir during off-peak hours, thereby leveling out the daily generated load. The energy used for pumping the water is derived from other energy sources, such as nuclear, fossil and renewable power plants, whose power output cannot be adjusted to follow load fluctuations. The stored water can then be used for hydroelectric power generation to cover temporary peaks in demand. The advantage of this technology is that it can come online very quickly, making it a useful tool to balance the varying electricity demand from consumers or unplanned outages of other power plants. Today there are over 130 GW of pumped storage in operation around the world, representing approximately 3% of instantaneous global generating capacity. In recent years, the profitability of pumped storage plants has increased as a consequence of increased price volatility on electricity spot markets.

The first use of pumped storage was in 1890s in Italy and Switzerland. In the 1930s reversible hydroelectric turbines became available. These turbines could operate as both turbine-generators and in reverse as electric motor driven pumps. The latest in large-scale engineering technology are variable speed machines for greater efficiency. These machines generate in synchronization with the network frequency, but operate asynchronously (independent of the network frequency) as motor-pumps.The world pumped storage generating capacity is around 120 GW. The five largest operational pumped-storage plants are listed in table 1below:

Station	Country	Capacity (MW)
Bath County Pumped Storage Station	United States	3,003
Guangdong Pumped Storage Power Station	China	2,400
Huizhou Pumped Storage Power Station	China	2,400
Okutataragi Pumped Storage Power Station	Japan	1,932
Ludington Pumped Storage Power Plant	United States	1,872

Table 1 List of five largest pumped-storage plants

The first pumped storage hydro power plant in India was commissioned in 1980 at Nagarujunasagar, Andhra Pradesh. Till now the capacity of pumped storage schemes installed in the country is 5804 MW. These are given in table 2

Sl No	Location	State	Capacity MW	Year of commissi oning
1	Nagarnjunasa gar	Andhra Pradesh	7x100	1980 - 85
2	Paithan	Maharashtra	1x12	1984
3	Kadamparai	Thamilnadu	400	1987 – 89
4	Kadana	Gujarat	4x60	1990- 98
5	Panchet	Jharkhand	1x40	1990-91
6	Ujjain	Madhya Pradesh	1x12	1990
7	Bihra	Maharashtra	1X150	1995
8	Srisailam	Andhra Pradesh	6x150	2001-03
9	Sarda Sarobar	Gujarat	6x200	2006
10	Purulia	West Bengal	4x225	2007-08
11	Ghatghar	Maharashtra	2x125	2008
12	Tehri	Uttrakhand	4x250	In progress
Total installed capacity MW			**5804 MW**	

Table 2 List of pumped storage schemes installed in India

II CLASSIFICATION OF PUMPED STORAGE SCHEMES

Pumped storage schemes can be broadly classified into the following categories.

A. Pure pumped storage scheme

In this type of pumped storage scheme electricity is generated by re-circulating water between lower and upper reservoirs. The same quantity of water is used for generation and also for pumping operation. The water loss due to evaporation, seepage etc. are met by some small inflows into the upper or lower reservoir. There is no conventional power generation at their power house. Power is generated only at peak load period. The sizes of these two reservoirs are almost equal. This scheme is found more feasible in the region where hydroelectric potential has already been developed.

B. Mixed pumped storage scheme

When a conventional hydroelectric power plant and pure pumped storage plant are combined, it is called as mixed pumped storage scheme. In this scheme, sufficient amount of inflow are available to this upper reservoir throughout the year or upper reservoir is too large and stores sufficient water to generate power most of the times of the year. In this case, the unit may be operated in the generator mode for some time during off-peak period. Therefore, the water used for pumping is more than that the water used for pumping. In some plants, sufficient water is available during monsoon and the run-off is drastically reduced during lean months of the year. So when sufficient water is available, power is generated in conventional method and during dry period, pumped storage method is adopted.

C. Pumped storage scheme to supplement the storage capacity of conventional hydro power plants

There are some locations which are very attractive for hydro power plants from the consideration of available head, but availability of water is not sufficiently large so that capacity of power plant is less. But simultaneously large availability of water is there in the nearby stream or river from where water can be pumped at relatively low head to the reservoir of the power plant. In this case, the scheme for pumping the water at lower head to the planned storage scheme is to utilize the available higher head for generating power through a conventional hydroelectric scheme. Pumping is done in off-peak duration.

III. PUMPED-STORAGE OPERATIONAL CONSTRAINTS

Pumped-storage stations usually have two reservoirs; the upper reservoir having little inflow, the lower reservoir is used to store the water after generation and will be pumped back to upper reservoir whenever cheap and surplus power is available. Reversible turbine–pump system along with synchronous machine is used for generating and pumping. Because of inherent losses, the power required for pumping water is more than the power that is generated by the same volume of water. This means that, for the plant cycle efficiency of çp$(0 < $ çp $< 1)$, after consuming energy of 1MWh for pumping water into the upper reservoir, the unit can only generate energy of çp (in megawatt hour) afterwards. Therefore, it is economical to bid for selling energy of çp (in megawatt hour) at a time period of tg with pumped storage generation, if there exists a time duration tp to bid for buying energy of 1MWh, such that the ratio of the MCPs during pumping and generating is less than the plant cycle efficiency of pumped-storage unit.

A. Plant Operating Time

Considering an operating cycle of T (in hour), the energy stored in upper reservoir, E_T(in megawatt hour) over the period T is given by

$$E_T = E_0 + E_{in} + E_p - E_g - E_L \quad (1)$$

Where E_0 is the initial stored energy in the upper reservoir, E_{in} is the inflow energy from river, E_L is the loss of energy due to evaporation during the period T. If the unit generates $P_g(i)$ (in megawatt) for $i = 1, 2, \ldots, t_g(h)$ and pumps at $P_p(i)$(in megawatt) for $i = 1, 2, \ldots, t_p$(in hour), the pumped and generated energies Ep and Eg are defined, respectively, by

$$E_p = \eta_p \sum_{i=1}^{t_p} P_p(i), \quad E_g = \sum_{i=1}^{t_g} P_g(i) \quad (2)$$

Assuming that the pumping power remains same during the entire period *tp* , the operating times *tp* and *tg* are related by

$$\sum_{i=1}^{t_g} P_g(i) = P_p t_p \eta_p - E_T + E_0 + E_{in} - E_L \quad (3)$$

The optimal operation of next successive operating cycles require energy balance in the upper reservoir, i.e., the stored energy at the starting and closing of the operating cycle is maintained same, i.e., $E0 = ET$. If the unit generates, at an average, Pg (in megawatt) for tg (in hour), then substituting $E0 = ET$, (3) reduces to

$$t_g = \frac{P_p t_p \eta_p + E_{in} - E_L}{P_g} \quad (4)$$

Assuming zero changeover time, using (4), the maximum pumping time within the operating cycle T can be estimated as

$$t_{pmax} = \frac{T - \frac{E_{in} - E_L}{P_g}}{1 + \frac{\eta_p P_p}{P_g}} \quad (5)$$

t_{pmax} can be used as the limiting criterion for optimization.

B. Market Clearing Price

Consider a real-time daily MCP curve for a typical restructured power market [10] shown in Fig. 1. The MCP peaks usually occur from 6:00 P.M. to 9:00 P.M., and the valley hours are from midnight to 6:00 A.M. From this, it is evident that pumping mode comes first and then the generating mode, in the daily operation cycle of pumped storage plant.

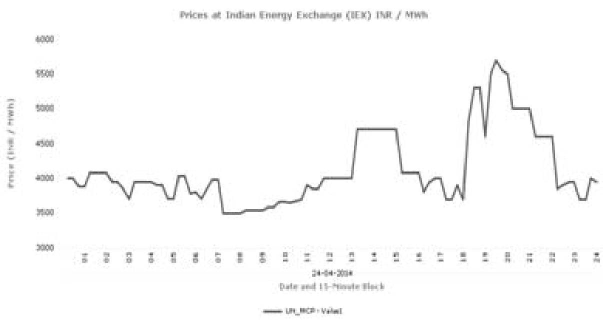

Figure 1: Hourly Market Clearing Price

Let *Bp* be the MCP (Rs/MWh) below which the plant buys energy from the market and pumps water for storage, and *Bg* be the MCP (Rs/MWh) above which the plant operates in generating mode and sells energy to the market. A composite MCP curve can be obtained by sorting MCP by ascending order. From the composite MCP curve, for the plant efficiency of *çp* , to be economically profitable, the condition to be satisfied for the marginal profit is given by

$$B_g \geq \frac{B_p}{\eta_p} \quad (6)$$

The typical value of plant cycle efficiency *ςp* is 67% [2]. Thus,

$$B_g = 1.5B_p \qquad (7)$$

C. Mathematical Model of Plant Operation

Consider a deregulated electricity market, in which uniform pricing equal to the last accepted offer (LAO) scheme is followed for computation of nodal prices. For a given hour, if the unit generates *Pg* (in megawatt) at *Bg* (Rs/MWh) in the generating mode, then it receives *Pg* × *Bg* (Rs). Similarly, if the unit pumps *Pp* (in megawatt) at *Bp* (Rs/MWh) in the pumping mode, then it pays *Pp* × *Bp* (Rs). The net revenue received from day-ahead market by selling energy during generating mode for *tg* (*h*) and buying energy needed to pump water into the upper reservoir for *tp* (*h*) is

$$\sum_{i=1}^{t_g} P_g(i)\, B_g(i) - \sum_{j=1}^{t_p} P_p(j)\, B_p(j) \qquad (8)$$

The pumped-storage unit can be committed for synchronous reserve market when it is operating in pumping mode, because it can readily serve as synchronous reserve by reducing its pumping power, which is equivalent to commit a generating plant, and consequently, reduce the overall system load. If the unit pumps at *Pp* (in megawatt) and able to reduce the power consumed for pumping from *Pp* to (*Pp* " *Prs*) during the reserve requirement, it can get paid for *Prs* × *Brs* (Rs), where, 0 d" *Prs* d" *Pp* and *Brs* (Rs/MWh) is the spinning reserve price. Revenue received from synchronous reserve market for *tp* (*h*) is

$$\sum_{k=1}^{t_p} P_{rs}(k)\, B_{rs}(k) \qquad (9)$$

When the unit is offline, it can be committed as a nonsynchronous reserve and get paid at *Pg* × *Brn* (Rs), where *Brn* (Rs/MWh) is the nonsynchronous reserve price. Revenue received from nonsynchronous reserve market by being accepted as a reserve for (*T* " *tp* " *tg*) (*h*) is

$$\sum_{m=1}^{(T-t_p-t_g)} P_g(m)\, B_{rn}(m) \qquad (10)$$

Operating cost of the unit during generating and pumping for (*tg* + *tp*)(*h*) is

$$\sum_{n=1}^{t_g+t_p} C_o(n) \qquad (11)$$

Considering fixed cost including maintenance expenditure of *Cm* Rs per *T* hours, the revenue over the period of *T* hours can be represented in the following equation:

$$R = \sum_{i=1}^{t_g} P_g(i)\, B_g(i) - \sum_{j=1}^{t_p} P_p(j)\, B_p(j) + \sum_{k=1}^{t_p} P_{rs}(k)\, B_{rs}(k) + \sum_{m=1}^{(T-t_p-t_g)} P_g(m)\, B_{rn}(m) - \sum_{n=1}^{t_g+t_p} C_o(n) - C_m \qquad (12)$$

To maximize the revenue of the unit, the plant operator require self-scheduling of pumped-storage for optimal duration of pumping tp_{opt} and generating tg_{opt} , during a cycle of *T* hours in the energy market. The strategy is to decide when to go for pumping/generation in the energy market, for how long and the corresponding power bids. Apart from that, the plant operator has to commit the unit in other ancillary services markets. The objective of this profit maximization problem is

$$Max\left(\sum_{i=1}^{t_g} P_g(i)\, B_g(i) - \sum_{j=1}^{t_p} P_p(j)\, B_p(j) + \sum_{k=1}^{t_p} P_{rs}(k)\, B_{rs}(k) + \sum_{m=1}^{(T-t_p-t_g)} P_g(m)\, B_{rn}(m) - \sum_{n=1}^{t_g+t_p} C_o(n) - C_m\right) \qquad (13)$$

Subject to the constraints of energy stored *E* (*t*) in the upper reservoir of the pumped-storage station, has an upper and lower limits given by

$$E_{min} \le E(t) \le E_{max} \qquad \forall t \in T \qquad (14)$$

D. Optimal Operating Condition

Being a discrete function with a step of 1 h, the condition for maximum revenue is obtained by making

$$\frac{\Delta R}{\Delta t} = P_g B_g \Delta t_g - P_g B_{rn} \Delta t_g - C_0 \Delta t_g + P_{rs} B_{rs} \Delta t_p - P_g B_{rn} \Delta t_p - P_p B_p \Delta t_p - C_0 \Delta t_p = 0 \qquad (15)$$

From (4), we have

$$\Delta t_g = \frac{P_p \Delta t_p \eta_p}{P_g} \qquad (16)$$

Using the previous equation and solving (15), we have

$$B_g = \frac{1}{\eta_p}\left[B_p + B_{rn}\left(\eta_p + \frac{P_g}{P_p}\right) - \frac{P_{rs}B_{rs}}{P_p} + C_0\left(\frac{1}{P_p} + \frac{\eta_p}{P_g}\right)\right] \qquad (17)$$

If the unit is allowed to reduce the complete load of Pp in order to bid in the synchronous reserve market, i.e., if $Prs = Pp$, (17) reduces to

$$B_g = \frac{1}{\eta_p}\left[B_p + B_{rn}\left(\eta_p + \frac{P_g}{P_p}\right) - B_{rs} + C_0\left(\frac{1}{P_p} + \frac{\eta_p}{P_g}\right)\right] \quad (18)$$

From (18), It is evident that the synchronous and nonsynchronous reserve market bids have significant impact on deciding the margin between bids for energy in generating and pumping modes for the optimal operation of storage plant.

E. Sequential Optimization Algorithm

The plant is self-scheduled for generating during peak price periods and for pumping during the valley price periods of day-ahead energy market. The optimal period of pumping t_{popt} and generating t_{gopt} during a cycle of T hours and corresponding power bids can be found by increasing the pumping time from zero to t_{pmax} and checking for the maximum profit. For the given pumping time tp, the corresponding generating time tg is estimated using the energy balance equation (4). In order to solve the constrained optimization problem given in (13), the following multistage looping algorithm is developed.

1) Read the forecasted MCP curve, equivalent energy curve, and power limit curves. Obtain composite MCP curve. Read the initial stored energy in the reservoir.

2) Start with $tp = 1$, for $tp < tp\max$, schedule the slots for pumping such that MCPs are minimum.

3) Start with $tg = 1$, schedule the slots for generating such that MCPs are maximum.

4) For $t = 1$ to T, $u = 1$ to N, adjust the stored energy at the end of each slot. When the unit is scheduled for pumping in the slot, if $Es < E\max$, then energy stored is increased by $çpPp$.

5) When the unit is scheduled for generating in the slot, then using the algorithm developed in Section II-E, find maximum possible Pg bid for the slot with respect to the slot's initial stored energy. If $Es > E\min$, then decrease the stored energy by respective value of Pg .

6) If the maximum or minimum capacity limits are violated while doing step 4) or 5), respectively, stop optimization at the previous slot and restart optimization again from the present slot, which is violating limit, taking latest energy stored as initial level $E0$ and keeping the final storage level as such.

7) Check whether (3) is satisfied. If it is satisfied, respective value of tg satisfies the energy balance and hence, go to next step. Else, repeat steps 3)–7) by taking $tg = tg + 1$.

8) Find the values of Bp and Bg corresponding to tp and tg , respectively, from the CMCP curve.

9) Check for optimality condition given in (17). If it is satisfied, make $tpopt = tp$ and $tgopt = tg$, and go to next step. Else let $tp = tp + 1$, and go to step 2).

10) Calculate the profit with (12). Print optimal schedule, pumping, and generating power bids and stop.

IV. simulation and Results

As an illustration, consider a pumped-storage power plant. The plant details are given as follows. The plant capacity = 100MW, active reservoir head = 80 " 125 m, $E\min$ = 1000 MWh, $E\max$ = 5000 MWh, $E0$ = 3500 MWh, pumping power rating Pp = 100MW, and plant cycle efficiency $çp = 0.6667$. The high and low power limit curves the upper and lower bounds on generation for the plant considered. The equivalent energy curve gives the amount of energy that can be generated by the plant as a function of head.

Assuming that the daily operating cycle starts from 0:00 A.M. and ends at 0:00 A.M. the following day with ET = 3500 MWh. Price forecasts for day-ahead energy market and ancillary services are obtained from the data posted on the Indian Energy Exchange website [10]. Market cleared energy prices April 24, 2014 are considered as the MCP forecast, which is shown in Fig. 2. It is assumed that the ancillary services market prices Brs = Rs:500.00/MWh and Brn = Rs:50.00/MWh, and remain constant over the operating period.

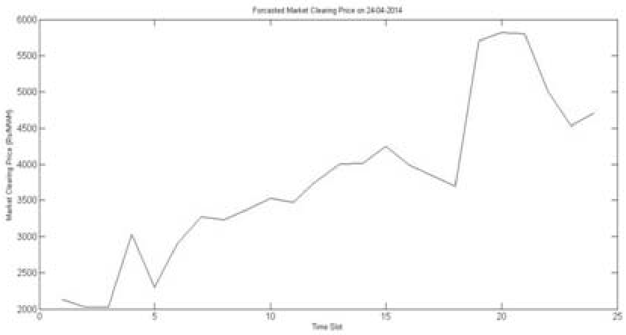

Figure 2. Forecasted Market Clearing Price on 24-04-2014 in Indian Energy Exchange

The bidding strategy developed in Section 2.2.2 is implemented and simulated in MATLAB 10.10.0 (R2010a). These are applied for two operating modes: daily operating mode and weekly operating mode, in order to test the performance of those algorithms and observe the variations in the different schedules. Both spinning and nonspinning reserve biddings are also taken into account for optimizing the generating and pumping power bids.

The energy storage in the reservoir with respect to time for a week corresponding to daily operating strategy are shown in Fig. 5.6 It is to be observed that for both the approaches, the energy balance is maintained. In the daily operating mode, energy balance is satisfied at the end of each day, whereas in the weekly operating mode it is satisfied only at the end of the week. This allows the weekly operating mode to operate at higher level of head, and hence, unit can be bid for higher generating power. The capacity of the reservoir is effectively utilized by the weekly operating mode rather than the daily operating mode. Optimal power bids for the same period from May 05 to 11, 2013 with respect to daily schedule are shown in Fig. 5.3 and with respect to weekly schedule are shown in Fig. 5. It is seen that the pumping mode falls on valley MCP period and generation mode falls on peak MCP period. The energy stored in the upper reservoir in each timeslot is shown in Fig. 6.

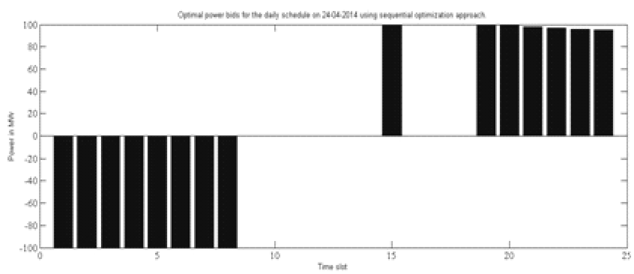

Figure 3 Optimal Power Bid for the daily schedule on 24-04-2014 using sequential optimization algorithm

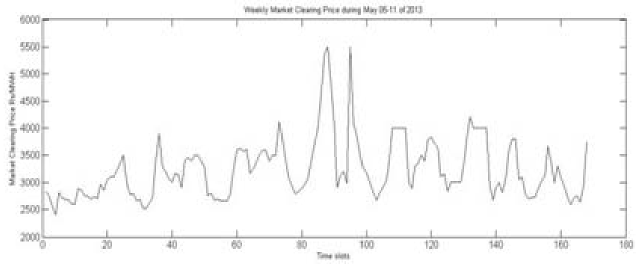

Figure 4 Market clearing price for the week from May 05 to11 on 2013.

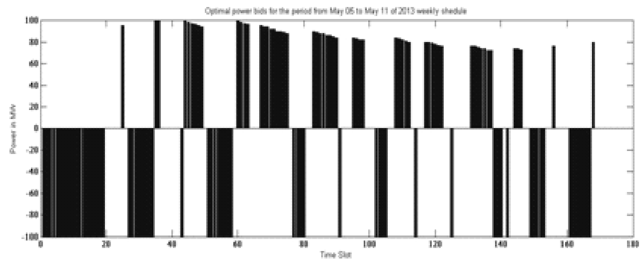

Figure 5 Optimal Power Bid for the weekly schedule from May 05 to11 on 2013 using sequential optimization algorithm

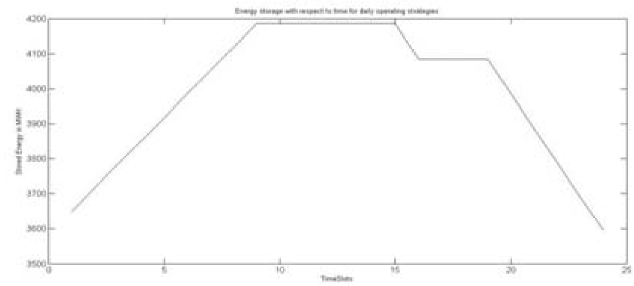

Figure 6 Energy storage with respect to time for daily operating strategies

V. Conclusion

In this work has provided a tool that allows a pumped-storage hydro generating plant to develop bidding strategy and optimally determine the short-term self-scheduling in the day-ahead energy and ancillary services market. Based on the forecasted Market Clearing Price curve, pumped-storage bidding strategy has been investigated in a pool-based competitive electricity market environment. A model to account for the nonlinear relationship between the energy stored, the power produced, and the reservoir head has been developed, taking into account, the reservoir capacity limit and power limits of the generator. Simulation results indicate the effectiveness in finding optimal self-schedules and expected profit for daily and weekly schedules.

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NOVAL TECHNIQUES OF CONDITION MONITORING OF POWER TRANSFORMERS

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ABSTRACT

Enhancing the reliability of the transmission and distribution equipment, reducing the operating cost is very much essential in today's deregulated environment. Cellulosic paper and oil are the major insulating materials in transformer and are subjected to different degradation processes during its life. Hence it is necessary to use new monitoring and diagnostic techniques for detecting the incipient fault before catastrophic failure. Currently there are varieties of chemical and electrical diagnostic techniques available for condition assessment of power transformer. In recent times recovery voltage measurement, polarization and depolarization current measurement and partial discharge monitoring using UHF technique are becoming more and more popular. This paper discusses the analysis and interpretation of these techniques in condition assessment of transformer insulation.

***Keywords**: Condition monitoring, furan analysis, recovery voltage (RV), polarization and depolarization current (PDC), frequency response analysis (FRA), partial discharge (PD)*

INTRODUCTION

Power transformer is the most important and expensive equipment used in power transmission and distribution system. They are required throughout the modern interconnected power systems. Power transformers are usually very reliable and are expected to operate up to 35 years.With proper maintenance the life of the transformer can be extended nearly up to 60 years. Extending the useful life of the power transformer has become the most important utility strategy for increasing the life of power transmission and distribution infrastructure. Monitoring systems can help to increase the transformer life and reliability of power transmission and distribution.

Quality of the electrical insulation is a key element for reliable operation of a power transformer. In transformers, cellulose paper along with oil forms the major insulation, which plays an important role in the life expectancy of the transformer. Insulation system can degrade at higher operating temperature and the degradation is accelerated in presence of moisture and oxygen [1].

During its operation transformers are subjected to various stresses, namely electrical, thermal and mechanical stresses leading to accelerated ageing. These stresses will result in chemical breakdown of the oil or cellulose molecules. The main degradation products are gases which entirely or partially dissolve in the oil. Dissolved gas analysis (DGA) allows one to detect the type of fault by analyzing the composition of gas produced during internal fault [2]. Non-destructive testing techniques such as dielectric response measurements are used to assess the condition of oil/ paper insulation. These methods include polarization and depolarization current (PDC) measurement technique and recovery voltage (RV) measurement [3].

Dielectric faults in the winding can occur due to mechanical displacement during transport or short circuit in power network. Such faults can be detected by frequency response analysis (FRA) [4]. Recently partial discharge (PD) measurements using ultra high frequency (UHF) technique is widely accepted due to its high sensitivity and low signal to noise ratio [5]. Condition monitoring techniques provide information on the developing insulation problems and incipient faults. Hence it is essential to use monitoring and diagnostic techniques to avoid early failure of the insulation. Due to the complexity of transformer a single diagnostic technique would not give sufficient information on the performance of the insulation system. This paper briefly describes the recent trends in condition monitoring techniques and diagnostic methods used in power transformers.

FURAN ANALYSIS

Paper is a major dielectric within a transformer, used either as conductor wrap and impregnated with oil or as barrier boards. Paper insulation is composed of complex cellulosic molecules containing long chain glucose monomers [6]. The number of monomer units in the polymer is known as degree of polymerization (DP) and the quality of cellulose is measured in terms of DP.

Due to overheating the cellulose structure undergoes slow decomposition and splitting of the chain liberates a glucose monomer unit that undergoes further chemical reactions to become furans (furfurals) and other products such as water, carbon oxide gases [7] - [8]. Most often the following five furan compounds are measured [9].

- 2- furaldehyde (2FAL)
- 5- methyl-2-furaldehyde (5M2F)
- 5- hydroxymethyl- 2- furaldehyde (5H2F)
- 2- acetylfuran (2ACF)
- 2-furfurol (2FOL)

Furan formation is related to the degradation of paper and gives information about DP. A reduction in DP value is accompanied by structural changes, reduction in average molecular weight and tensile strength of paper [10].

Normally for a fresh sample of cellulose, the DP is in between 1000 and 2000. As the insulation ages under thermal load, this value continuously decreases and it reaches below 250 indicating an end of life [11].

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Burton et al. made a study of rate of furan formation of several furan products over a wide range of temperature (120^0C”350^0C). They observed that the decrease in tensile strength of the paper correspond to an increase in the concentration of the furans in the oil [12]. The rate of rise of percentage of Furfurals products in oil, with respect to time, is used for assessing the condition and remaining life of paper insulation in power transformer. The solubility of these compounds in oil is quite appreciable and their concentration in oil can be detected using High performance Liquid chromatography [13].

DIELECTRIC RESPONSE MEASUREMENT

Dielectric response measurement refers to a family of methods used for characterization of dielectric materials. Conventional methods of measuring dielectric response include capacitance-tan delta measurement and measurement of insulation resistance. Recently, measurement techniques such as return voltage methods (RVM), polarization and depolarization current (PDC) measurements are becoming more and more popular. These methods could be used as an effective tool for transformer condition assessment.

III.1 Return voltage measurement

The degradation of insulation system in a power transformer depends on thermal, electromechanical and chemical stresses. Under these stresses decomposition of cellulose takes place and produces water in the solid insulation, which acts as a catalyst for further degradation. The breakdown voltage of insulating oil and paper is reduced with increase in moisture content of oil. Thus knowledge about moisture content (conductivity) can be used as an important basis for condition assessment of the oil/paper insulation

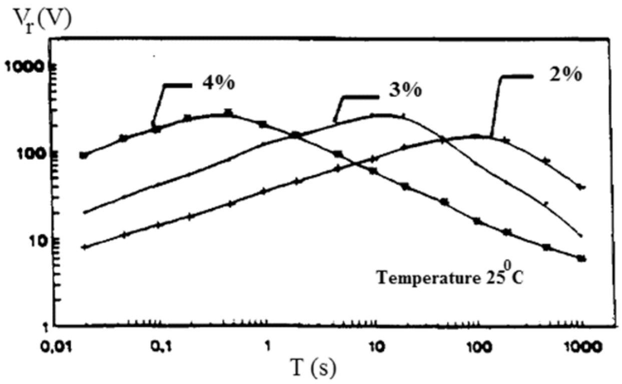

Fig. 1. RV spectra of oil impregnated paper [17]

Recently Return voltage measurement technique is used to detect the water content and ageing process of oil/ paper insulation [14].When a dielectric material is charged with an electric field, it gets polarized. In RV measurement the sample is charged for a long period of time and then the sample is isolated from the high voltage source and short-circuited for a short duration. When the short circuit is removed the charge bounded by the polarization will turn into free charges and voltage will build up between the electrodes on the dielectric and can be measured [15]. The time constant associated with this voltage gives an indication of the condition of the insulation. The relevant parameters associated with this measurement are the maximum value of the voltage, the time to peak value and the initial rate of rise of the return voltage [16]. Fig.1. shows typical RV spectra of oil impregnated .The absorbed moisture and temperature of the oil/paper insulation affect the return voltage measurement. Therefore return voltage measurement is always carried out at ambient temperature (20^{0}C”30^{0}C) [18].

III.II Polarization and depolarization current measurement

The principle of this measurement is based on the application of a dc voltage across the test object for a long time (‘~1000seconds). During this time the polarization current is measured. Then the voltage is removed and the test object is short circuited, and the depolarization current is measured [19]. Fig.2. shows principle diagram of this method. Polarization current is built up of two parts, one part is related to the conductivity of the test object and other is related to the activation of the different polarization processes within the test object. Initial part of the polarization currents depends on the condition of oil and final values are influenced by the condition of solid insulation [21]

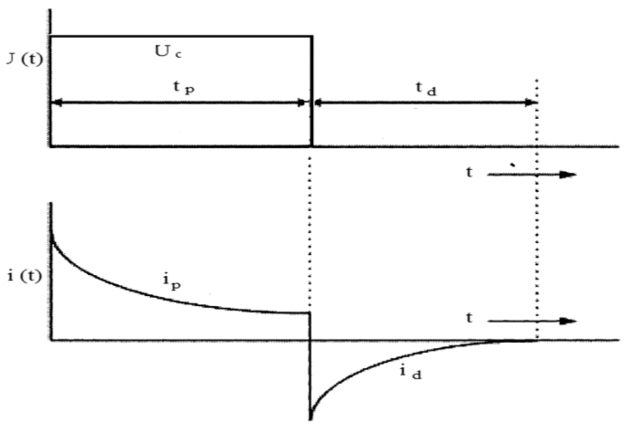

Fig. 2. Principle of polarization and depolarization current easurement [20]

. Saha et. al [22] studied the influence of oil and paper conductivities on PDC and concluded that changes in paper conductivity affects the tail of both polarization and depolarization curve and initial higher magnitude of conduction current is due to the higher mobility of charge carriers present in oil . In general it can be concluded that moisture and other contamination tend to increase the paper and oil conductivity and in turn affect the PDC.

FREQUENCY RESPONSE ANALYSIS

During normal operation, transformers are subjected to several short circuit forces that can cause deformation or displacement of the windings as well as changes to winding inductance or capacitance of the transformer. Such small movements may not be detected through conventional condition monitoring techniques. Sweep Frequency Response Analysis (SFRA) has turned out to be a powerful, non-destructive and sensitive method to evaluate the mechanical integrity of core, windings and clamping structures within power transformers by measuring the electrical transfer functions over a wide frequency range [23].

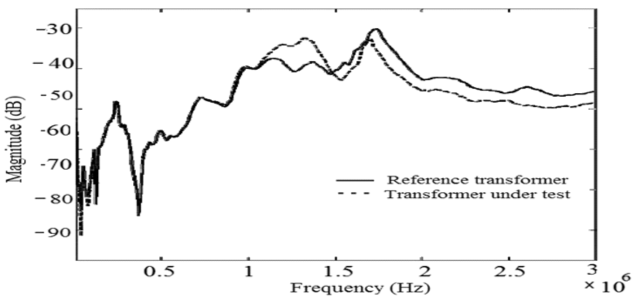

Fig. 3. FRA test results [28]

This technique is based on the principle that every transformer winding has a unique signature of its transfer function that is sensitive to changes in the parameters of windings such as resistance, inductance and capacitance [24]. Difference in signature of the responses may indicate damage to the transformer, which can be investigated further using other techniques or by an internal examination.

There are two different testing techniques- Sweep frequency response analysis (SFRA) and impulse frequency response analysis (IFRA) [25]. SFRA is usually done by injecting a sinusoidal signal of variable frequency into one terminal of a transformer winding and measuring the response signal on other terminal .With impulse response analysis, a pulse signal is applied to HV winding and response is recorded in the other winding. In general FRA technique is a comparative method in which measurements are made over a wide range of frequency from 50Hz to 5MHz and compares the results with a finger print measurement or with a reference response taken during installation [26]. Tenbohlen et.al [27] made a comparative study of the two FRA methods and proved that sweep frequency method is superior to low voltage impulse method in detecting mechanical damage to transformer winding. Fig.3 shows a typical FRA curve, with and without fault.

ON LINE PARTIAL DISCHARGE DETECTION METHODS

Partial discharges are localized electrical discharges within the insulation system and can deteriorate the insulation and cause complete failure of the system and hence it is desirable to monitor on line. The following are the various types of defects causing partial discharges (PD)

1. Impact of moving particles on the enclosure or on the insulation surface
2. Electrode protrusions
3. Fixed particles on an insulating surface
4. Floating electrodes causing a very large energy PD
5. Voids in solid insulation

PD activity is associated with both physical phenomena and chemical changes within the insulating material. During PD can cause transmission of electrical, chemical, acoustic and optical energy [29]. Conventional method of identifying incipient discharge is through measuring the degradation products produced during discharges, identification of luminous discharges and by measuring the partial discharge magnitudes. DGA results alone cannot establish the location of fault.

Conventional electrical method according to IEC 60270 of PD detection is based on the measurement of apparent charges generated due to different defects. This method has certain limitations such as low sensitivity and poor signal to noise ratio when applied to on line PD monitoring [30]. PD detection and location in oil paper insulation systems were achieved by the use of High Frequency Current Transformer (HFCT) and Inductive Loop Sensor (ILS) [31].

Currently onsite PD detection with high measurement sensitivity are gaining importance and this can be achieved by UHF or acoustic emission (AE) techniques.

Acoustic detection of PD is based on the retrieval and analysis of ultrasonic pressure pulses (20 kHz – 1.5 MHz) propagating through insulation due to partial discharges [32]-[33]. These pressure waves propagate through the medium and interact with the walls of the equipment and setup small amplitude vibrations. The signals thus generated can be detected by appropriate acoustic sensors mounted outside the transformer tank.

PD detection and localization in oil filled transformer was carried out by Lu et.al [34]. Sakoda et.al [35] made an attempt to detect corona discharges in oil using AE sensors placed outside the tank. The detected AE signals were analyzed by Fast Fourier Transform (FFT). It is a non-destructive testing technique and which can be applied to on line PD monitoring. Also location of PD defective site is possible using multiple sensors placed at different locations but this method of PD detection is limited by signal attenuation.

PD injected current pulses have duration of the order of 1ns or less, accompanied by electromagnetic radiation in ultra-high frequency range of 300MHz -3GHz.The resulting UHF radiation can be coupled to a designed capacitive device [36]. The UHF technique is being increasingly applied to the diagnosis of defects in gas insulated system and recently in case of power transformers and it is proved to be much more efficient than acoustic emission when the signal path passes through the solid insulation [37]. Judd et al. [38] conducted studies on PD activity using UHF sensor on a 18MVA, single phase 132/25kV traction transformer

UHF sensors must have a broad band response because the frequency content of the signals from defective site can vary considerably depending on its location and signal path [39].

CONCLUSION

In this paper an attempt has been made to understand the diagnostic techniques commonly used in power transformers. With regular monitoring and diagnosis it is possible to extend the life of a transformer. Among the chemical methods used DGA is the most widely used method for investigating incipient faults. Furan analysis is used to investigate cellulose ageing phenomena and it is related to degree of polymerization. Dielectric response measurement techniques such as FRA technique are suitable in finding the winding displacement or deformation. Recovery voltage measurements with the help of dielectric theory and polarization and depolarization measurements are good in investigating the moisture content of oil/paper insulation. Recently on line PD measurement is possible with the help of UHF sensor which is a broad band sensor gaining more importance due to its high sensitivity and less signal to noise ratio.

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Estimation of Sediment Yield in coal mining area using Model builder- a geo informatics approach

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Abstract

Electricity is a critical input need for the development of any country. In India Coal is the bulk source for the primary energy. Indian power sector used about 400 million tonnes of coal in 2011-2012 which is almost 60% of the total demand. Economic development and environmental quality are equally important in the growth of community. Coal dust and land reclamation are cited as the significant issues in coal mining. In this paper an attempt is made for the estimation of the sediment yield generated in a mining watershed. The paper deals with the quantitative measurement of soil erosion using spatial approach. The paper addresses the case study from Erai watershed in Maharashtra western coal field limited. The GIS based sediment assessment tool is used for estimation of soil erosion in the mining watershed area. Soil erosion/ sediment yield model builder tool put forward by Donghyeok and Wonheewoo is used in the study.

1. INTRODUCTION

In India more than 60% of commercial energy demand is met through country's vast coal reserves. Environmental degradation is one of the major threats faced due to mining activities. Accelerated soil erosion is resulted due to the human induced activities likes mining, construction and agricultural activities which disturb the land surface .It has been estimated that in India about 5334 m-tonnes of soil is being detached annually due to various reasons and about 113.3 m ha of land is subjected to soil erosion due to water (Babu 1983) (Jain MK 2001). Soil erosion also affects soil productivity by changing soil properties and particularly by destroying topsoil structure, reducing soil volume and water holding capacity, reducing infiltration, increasing run-off, and washing away plant nutrients, such as nitrogen, phosphorous, and organic matter.

2. KEY WORDS

Sediment yield model builder, Arc Map

3. STUDY AREA

The study is carried out in Chandrapur district of Maharashtra located 18 ^{0} and 20 ^{0} 50 ^{0} north latitude, 78 ^{0} and 80 ^{0} 60 east longitude. Chandrapur district is rounded by Bhandra and Wardha in north, Godichiroli in east, yaratmal on west and Adilabad district of Telugana state in south. According to census 2011 Chandrapur had population of 2204307 with 193 people per sq.km. It has about 12 coal mine.

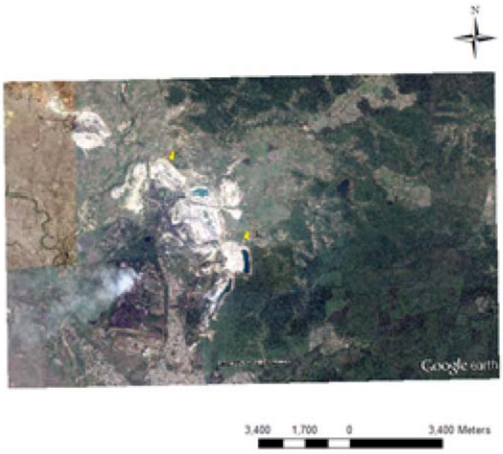


Figure 1: Study area Erai watershed

4. METHODOLOGY

Estimation of sediment yield using soil erosion/ sediment yield model builder tool

The GIS based sediment assessment tool is used for estimation of soil erosion in the mine dump watershed area. Soil erosion/ sediment yield model builder tool put forwarded is used in the study (wonheewoo 2008). In the arc tool box of Arc GIS Envsys_soil erosion tool is added. The GIS integrated prototype version which uses same parameters used in universal soil loss equation is used to estimate soil erosion from the mine dumps.

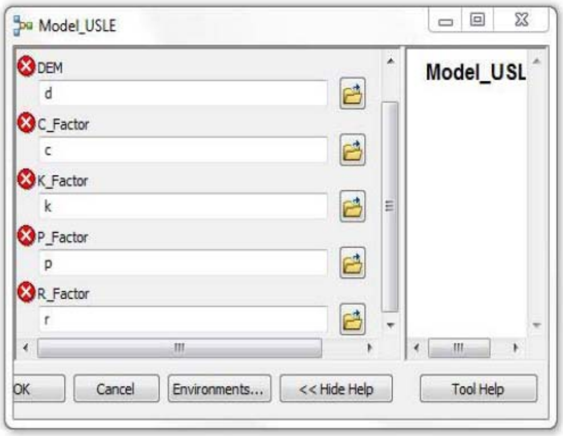
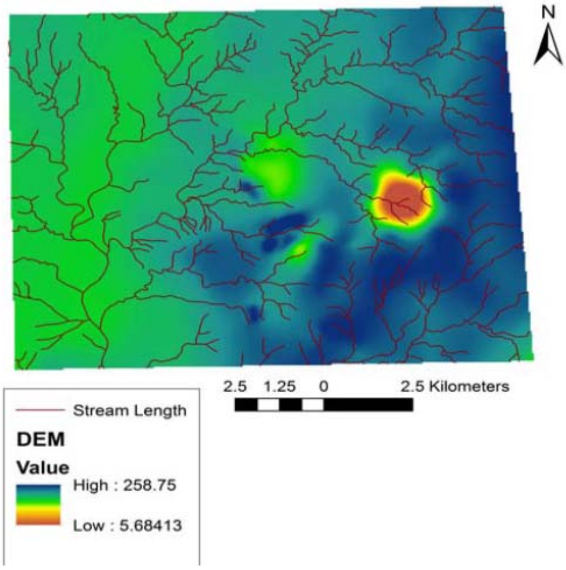


Figure 2: Model builder window

4.1 Digital elevation model (DEM)

Using the Google earth the points at suitable location on the mine dumps are marked. The elevation of the points were simultaneously and manually recorded from Google earth, which were then taken into the attribute table for respective points. The Topo to Raster tool in Arc GIS is used to construct the digital elevation model (DEM).



4.2 R factor

R factor is the rainfall and runoff factor governed by geographic location. R factor for Erai sub watershed computed from rain gauge data. R is the rainfall runoff erosivity factor. The daily rainfall data was collected from Indian meteorological Department (IMD) and Maharashtra Agricultural Department of last 12 years.

Table:1 Value of R factor for the period of 12 years

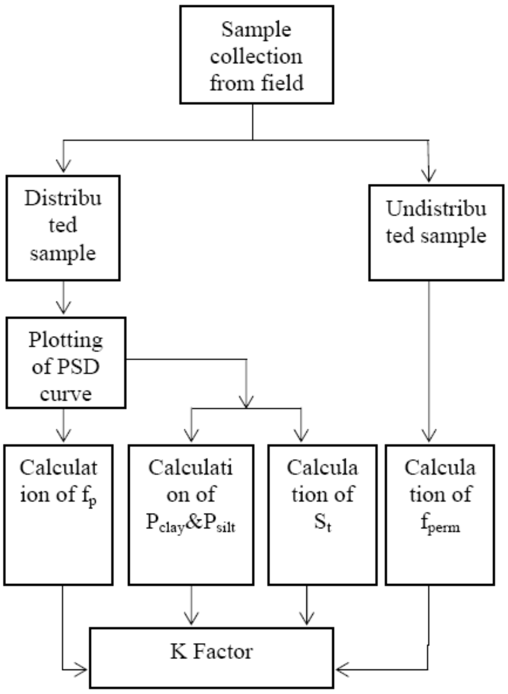
R Factor	
2002	291.23
2003	683.84
2004	156.55
2005	456.44
2006	561.29
2007	411.6
2008	1004.15
2009	95.55
2010	369.13
2011	370.78
2012	111.525
2013	133.6
R Factor= 383	

4.3 K Factor

K is the soil erodibility factor. Soil erodibility factor 'K' represents both susceptibility of soil to erosion and rate of runoff as measured under standard unit plot.

$K_f = 1.292 * [2.10*10^{-6} * fp^{1.14} * (12 - P_{om})] + .325 (S_{st} - 2) + .025 (f_{perm} - 3)$

In which $f_{perm=} p_{slt} (100 - p_{clay})$, f_p is the particle size parameter (unit less), p_{om} is the present organic matter (unit less), s_{st} is the soil structure index (unit less), f_{perm} is the profile permeability class factor (unit less), p_{clay} is the percent clay (unit less), p_{slt} is the percent silt (unit less)



Flow chart 1. Flow chart showing steps involved in K factor calculations.

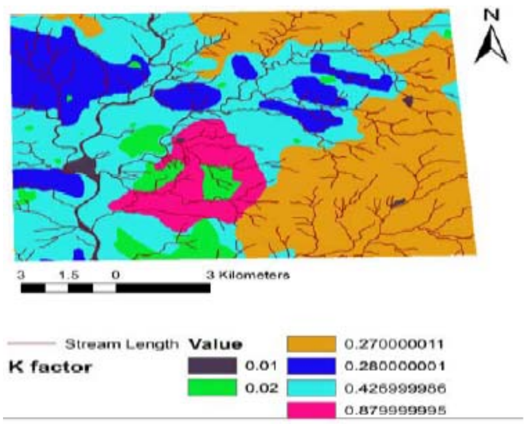


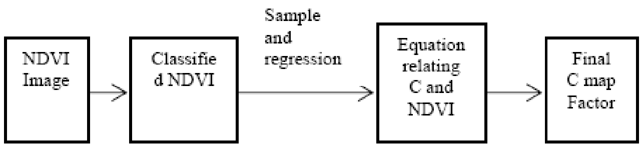
Figure 4: K Factor values for the calculation of sediment yield

Table 2: K Factor values

#	Soil texture type	K Factor
1	Habitation mask	.02
2	Mining	.88
3	Gravelly sandy loam	.427
4	Sandy clay loam	.27
5	Clay loam	.28
6	Water body mask	.01
7	Sandy loam	.27
8	Gravelly sandy clay loam	.14
9	Clayey	.17

4.4 C Factor

The effect of vegetative cover on erosion of soil is taken in C factor. The value C=1 means absolutely no cover effect and soil loss comparable to that from bare land. The value C=0 means heavy cover effect and no soil loss



Flow chart 2. C factor calculation

C Factor = 1.14255548474972-(3.14977864202)*NDVI ---2

Table 3: NDVI and C Factor values for various classes

Land Class	Average NDVI value	C factor
Water Bodies	-.229	0
Dense Vegetation	.28	.259
Moderate Vegetation	.11	.796
Very Sparse Vegetation	.0506	.980
Sparse Vegetation	-.05	1.299
Barren Land	-.06	1.330

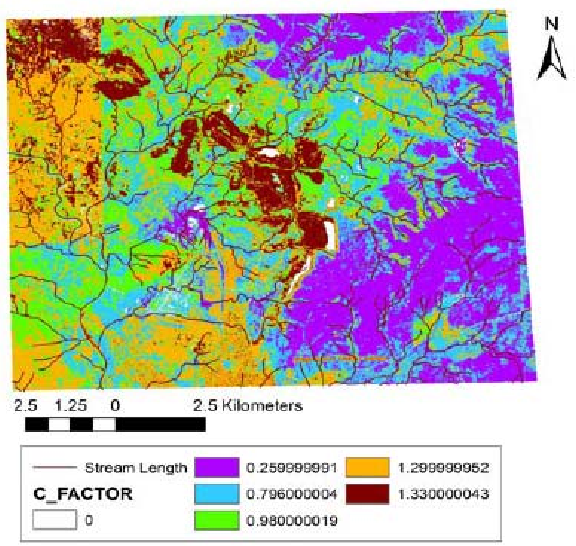


Figure 5: C factor values for the calculation of sediment yield

4.5 P Factor

P factor is the ratio of soil loss with conservation practices like contouring, strip- cropping or terracing to that with straight row farming up and down the slope. For the dumps it is assumed that no special practices (terracing, contouring etc.) and the P factor simply left 1.A value of 0.7 is given for the non-dumps area to incorporate all other practices.

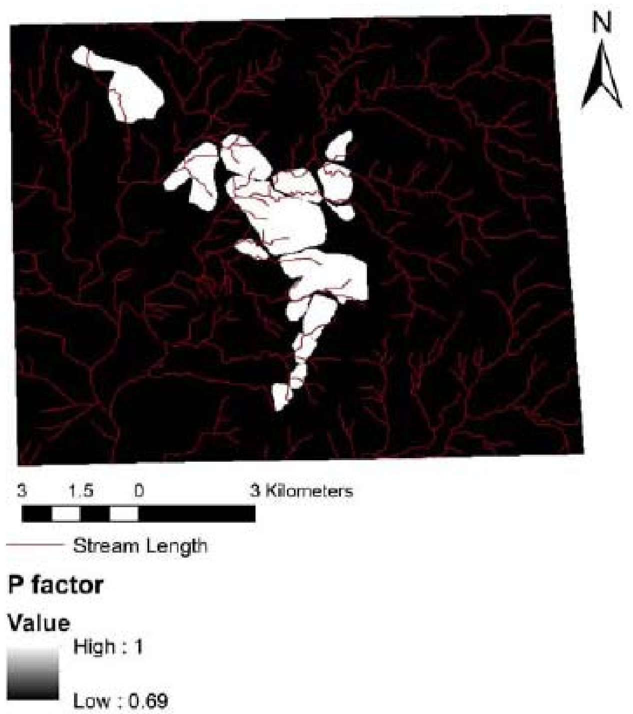


Figure 6: P factor for sediment yield calculation

4.6 Soil erosion

Soil erosion/ sediment yield model builder tool calculate the soil erosion value of the mining watershed area as 33029.29 tones/hectare/year.

4.7 Sediment yield

Sediment yield of the catchment is found by multiplying the soil erosion value with the corresponding sediment delivery ratio of the watershed. Sediment delivery ratio can be found by the equation put forwarded by Boyce in 1975, (R.C 1975)

$$SDR = .3750*A^{-.2372} \quad ---(3)$$

Where A is the catchment area in kilometer square For this case study catchment area is 162.2 kilometer square and the sediment delivery ratio is found to be 0.112.

Sediment yield value obtained for the mining watershed is 3666.32 tone/hectare/year.

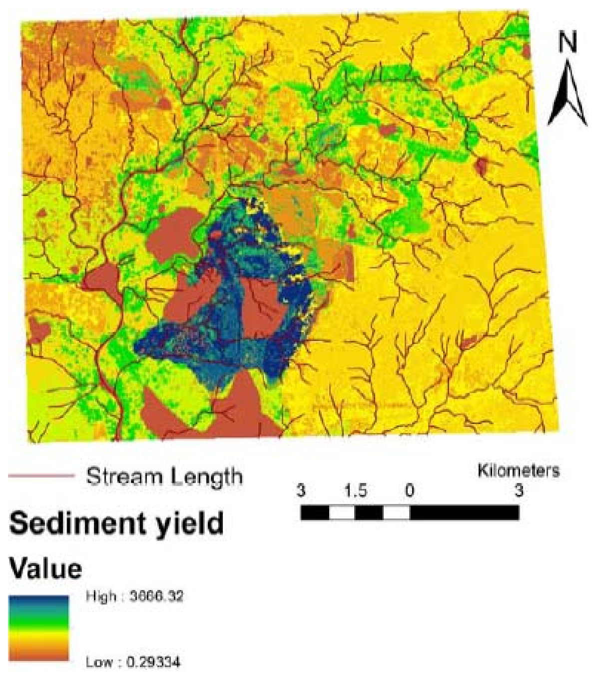


Figure 7: Sediment yield value

5. CONCLUSION

- The sediment yield in the area is high due to the presence of mining area. Check dams can be constructed which will intersect the flow and in turn control the flow of sediment discharge.

- Sediment assessment tool for effective soil erosion control will help to analyze the sediment yield of an area in an effective way using USLE input data.
- Devolvement activity under consideration should be economical stable and environmentally sound.

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KSEBEA Code of Ethics

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- Thou shalt incessantly work for the advancement of the professional knowledge.
- Thou shalt not give an incorrect professional opinion
- 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.