PUBLIC UTILITIES COMMISION OF SRI LANKA

Off-Grid Electrification using Micro hydro power schemes- Sri Lankan Experience

A survey and Study on existing off-grid electrification schemes

4/10/2012

The report contains a summary of findings, technical observations, protection schemes and existing safety related issues, technical issues associated with Grid connection of these plants, and Socio economic aspects associated with operation & maintenance, community specific observations, and future sustainability of these off grid schemes from developmental perspective.

Off-Grid Electrification using Micro hydro power schemes- Sri Lankan Experience *(A survey and Study on existing off-grid electrification schemes)*

Introduction

Despite having a very good level of grid penetration, off grid electrification schemes are still ubiquitous in Sri Lanka. Currently we are having a grid penetration level of 89% owing to the systematic grid expansion projects carried out by utilities, and policy decisions of governments which caused extension of national grid to every nook and corner of the country. However marginal costs of this has not been carefully assessed and compared against economic benefits derived in national level. Due to lack of loads, some lightly loaded sections of distribution network require 15to 20 years of payback period (to return the investment made on grid expansion. Grid parallel or grid independent Distributed Generation becomes particularly relevant in this context. This study mainly aims to provide an objective picture regarding the present status of off-grid electrification schemes in Sri Lanka, which is dominated by Pico, and micro hydro schemes and attempts to analyze the technical issues and challenges in the light of theoretical knowledge.

Summary of findings

Most of the Village Hydro Schemes (VHS) in Sri Lanka are aided by RERED project funded by World bank and global environment Facility (GEF) these initiatives have established 100-150 Village Hydro Schemes in the country with capacities ranging from 3-50kW. We have inspected a selected set of off-grid schemes which have submitted applications for exemptions from generation and distribution licenses, for compliance with safety regulations and substandard constructions. This together with information gathered from inspectorate in previous projects, provided the awareness which is imperative for the task, and some valuable insights on community based model of development.

Location

Most of the VHS are located in Rathnapura and, Kegalle districts while there are some in Deniyaya, Nuwara eliya and Kandy. Located in Wet zone, and being difficult to reach by national grid are factors which have fostered mini-hydro development in these areas.

Plant Capacity

Out of VHS considered for this study, the minimum plant capacity was 7.5 kW while the highest being 45kW. Generally plant capacities of micro-hydro schemes ranges from 5kW to 50kW. It is the hydro potential of the location that mainly determines the plant capacity and sizing while the availability of finances too plays a significant role here.

Generator type

All except one VHS which we have visited uses Induction generators. There was one power plant that has used a Synchronous generator. There were no sites with inverter based systems which is widely popular in European countries and is extensively used for wind and solar power integration. This is mainly due to the high capital cost of inverter. Other than better power quality which matters especially when it comes to future grid connection, there are no significant benefits of using inverter system compared to the additional costs.

Number of Consumers

The number of consumers of these schemes varies from 17 to 116. Electricity Consumers societies can benefit from per consumer cost as number of consumers increases, which allow the societies to operate charging lower fixed charge per connection. But unlike in urban areas, population is more dispersed in these areas and maintaining the distribution system safe and up to standards becomes a serious challenge. Inspection reports on accidents by Inspectorate reveals that some of the most unfortunate accidents related to off grid schemes have occurred in societies with relatively high number of consumers.

Standards of domestic Wiring

Though there are some reportedly unsafe installations, there are many installations in satisfactory condition. Generally the standards are better compared with the rest of South Asian region as using protective devices like RCD’s MCB’s is popular in Sri Lanka. Sub standard constructions in distribution system is more critical issue in Sri Lanka.

1) <u>Technical observations</u>

All these micro hydro schemes mainly consist of a weir, cannel, Penstock, turbine, generator and control system, and the distribution system. Hydrological studies and other design work required for these projects are carried out by companies and NGO's that have provided technical assistance to these village electricity co-operative societies and there are identifiable tradeoffs between cost and optimum technical design.

Penstock

Most of these VHS are equipped with HDPE penstocks which are unnecessarily long and are not laid and jointed in optimum way to reduce head loss. Better hydrological studies could have avoided such lapses. Using higher diameter pipes could also have reduced head loss by reduced velocity. In addition to that the needs of maintaining eco-flow of the waterways, availability of water resource, are likely to have imposed some constraints on optimal design. Not doing proper hydrological studies can result in high civil engineering costs due to say too long canals, (low pressure tunnel) or penstock and also causes underutilization of precious water resources.

Turbine

All village hydro schemes we have visited including sites observed by inspectorate before, have small Pelton turbines except one which had cross-flow turbine. The high efficiency of Pelton turbine through broad range of flow rates is the prime advantage of using Pelton turbines instead of Francis or any other reaction turbine. Using Pelton turbine also release the design and construction engineers from accounting for draft tube and maintaining required water level at tail race. However high maintenance cost of impulse turbine compared to reaction types becomes disadvantage. Though we don't have hard facts and statistics for comparison (due to lack of VHS that use reaction turbines) a scheme with reaction turbine is theoretically likely to have low vibration levels and reduced maintenance costs. The new cross-flow turbine too boasts about low maintenance and consistent behavior under partial load conditions because it works at constant efficiency under varying flow rate. But the efficiency of the cross-flow turbine is still generally low compared to other counterparts, which becomes a drawback. Meanwhile, the low inertial of small turbine can be a factor to be considered when it comes to grid connection. This aspect will be discussed in *'Grid Connection'* Section.

Generator

All except one VHS (Katepola Umangedara VHS) we considered are using induction generators for their power plants. Induction machine is driven about 5%above its synchronous speed by using the turbine as the prime mover. The power available in the site is calculated in the design phase by considering flow rate and Head when hydrological studies are being carried out and this is taken into account when selecting the generator and turbine. The kW rating of the induction motor has to be more than power available in the site because its customary to apply a derating of 20% when induction motor is operating in generator mode as machine runs hotter in this mode. All the distribution systems except Katepola Umangedara VHS are using C-2C capacitor connection to obtain single phase supply from 3phase machine. [1] This releases system from the burden of balancing 3phases in a scheme with limited number of consumers. The advantage of uniform power flow associated with three phase system cannot be exploited here because feeders extend to geographically different directions and the advantage of having a balanced system outweighs this disadvantage. However inability to connect three phase loads in future is a disadvantage.

Recommendations

- Some VHS have experienced failures and repairs of their Induction Machines and have incurred significant amounts of money for such recurrent repairs. Hence, it is advisable to make using IP 55 certified generators mandatory, to minimize damage due to water and moisture.
- Generator runaway conditions can occur in an event of failure of ballast load under lightly loaded conditions. Since there are no mechanical power controls, the turbine and generator will accelerate to runaway speed. Generator voltage will increase as a result of runaway situation and this can cause serious damage to generator windings and insulation [1]. Therefore, appropriate over voltage protection or voltage vector surge protection should be applied to provide protection in such scenarios.

Controller and Dump Load

Almost all schemes have used locally manufactured Induction Generator Controller (IGC) with dump loads, for active power control. There is no reactive power control as capacitors connected for excitation and magnetization of induction machine are of fixed values. VHS are compelled to use IGC as using hydraulic controlled wicket gates to control flow rate and hence the active power of the generator is not economical viable in this scale. Therefore the generator is set to run at its rated speed and frequency control is achieved by varying the dump load connected to the generator.

There are two methods of implementing the IG Controller with dump load. One is adding step loads to the generator as frequency drops, by switching on heating elements of dump load bank, while the other is using power electronic devices. The latter method uses two anti parallel thyristors with a resistor [1] and controlling the load by changing the firing angle of the thyristors. However this method draws reactive power when ballast load is operated at partial load. Using a method of directly adding step load instead, requires switches that can handle significant currents involved with dump loads which can be expensive.

However most of the Controllers in VHS are not in operating condition due to lightning surges and other various faults. In such cases the dump load is permanently connected to the system and the active power is controlled by the inlet value connected to turbine jets, from time to time as loads change in different hours of the day. This does not serve the purpose of having a dump load.

Recommendations

- Having an IGC which functions properly, is imperative for VHS especially when there is a proposal for grid connection of these power plants and therefore all these IGC's have to be repaired as soon as possible.
- The dump loads used in all these VHS are resistive heating loads with sizes from 2.5kW to 12kW which is a considerable waste of energy even in conditions where IGC is functioning properly. Coupling another load like grain mill or saw-mill, to the generator shaft, directly or through a mechanical clutch, can effectively utilize the energy being dissipated as heat through dump loads. This is successfully implemented in other similar projects. The connection or disconnection of this motive load can be considered equivalent to increase or decrease of total system demand for analysis purposes and therefore the control algorithm of IGC need not have to be modified.
- It can be assumed that lightning surges is one of the main reason for this failures of IGC as most of these power plants are not equipped with lightning protection schemes. And few of the power plants which have used lightning protection by low cost elementary spark gaps, still have shown significant reduction of lightning strikes and failures (eg. Ballahala Village Hydro Scheme). Therefore it is advisable to use lightning protection for all VHS at least by spark gaps.

Distribution system

Most of the VHS have used all aluminum conductors for distribution systems. G.I. wires had been used for stays and struts in most of the cases. Many distribution schemes uses wooden posts made out of wild trees from the area as poles of distribution system while many societies are in the process of fabricating concrete poles by revenue of electricity co-operative society and labor contribution of villagers. Live wild trees are used as poles in some VHS which is an extremely dangerous practice.

Information was not available regarding the losses of distribution system neither was data required to calculate them. There were no complaints regarding power quality problems like voltage dips due to long feeders, or surges due to sub-standard distribution systems, though occasional interruptions due to fault trippings were common sight. However these were not due to an issue of protection schemes and settings used, but sub-standard constructions like 'Live wild trees'. Some similar Village Hydro schemes of other countries like Nepal, uses load limiters made by PTC's for each individual household to limit power consumption [2]. However no VHS we have come across here have used such mechanisms.

Recommendations

- The compliance to safety and technical standards of the distribution system should be inspected and certified by a qualified personal before granting exemption
- Plant operators shall be required do monthly routine inspection of feeders for damages, wayleave problems due to new constructions or any such construction which can be a significant danger to public and take corrective measures as reasonably practicable. They shall also maintain a log book regarding such inspections.
- Evaluating the possibility of using insulated conductors instead of bare conductors as this can significantly reduce accidents even at premium cost. At least using insulated conductors when distribution system geographical spans more than certain limit (square kMs) is advisable as inspection reports on accidents suggests a correlation between accidents and the number of consumers connected to the scheme. (which can be an indicator of the geographical area through which the distribution system spans) This shows that maintaining wayleave clearances and safety standards becomes more challenging when the distribution system spans through larger area. Hence using insulated conductors would be effective way to avoid accidents in such cases. Furthermore insulated conductors are less prone to lightning strikes, which further justifies the premium cost, in long term.
- No data was available regarding power losses and voltage drops of the distribution system though studies related to that might have been carried out in initial design phase. Especially in isolated systems which operates with compromised power quality standards, losses and voltage drops associated with distribution system can be significant. Therefore it is advisable to make doing a reasonably practicable prior study and design of distribution system, mandatory.

2) <u>Protection schemes and Existing Safety related issues</u>

Electricity safety is a prime concern when it comes to exempting these Village hydro Schemes from generation and distribution license. Being isolated from national grid makes it difficult monitor their compliance to safety standards and therefore steps should be taken in designing and construction phase, to ensure that risks will be minimized in operational phase. Furthermore, since safety regulations are applicable to even exempted parties, relevant reporting requirements have to be fulfilled by these Electricity Consumer societies.

Some of the safety related issues had been discussed in some preceding sections and this section attempts to discuss any other identified problems/challenges. Especially when Grid connection project is launched, attention should be given to prospective issues related to protection schemes due to incongruence between protection schemes of national grid and island system. Earthing impedance, feeder protection schemes can be problematic in this regard. Therefore in case of grid connection, it would be better to hand over control of distribution scheme to CEB for grid connected operation. The plant alone can be maintained by Consumer society.

Live wild trees and sub standard Distribution System

Many of these off grid mini hydro schemes uses live wild trees at least in some locations of their distribution system. This is seriously dangerous practice especially because almost all of them use bare conductors instead of insulated conductors due to cost concerns. This is a very dangerous practice that has resulted in many accidents in the past. Generally attention to safety of distribution system is minimal at the beginning of a village hydro scheme from consumer's point of view and whatever measures taken to ensure electrical safety, had been taken by developers. Hence we can notice that safety standards have been seriously compromised in cases where involvement of a developer is minimal. Inspections carried out by inspectorate suggest that most of the accidents occur in these village hydro schemes are due to sub standard distribution systems

Recommendations

Most of these off grid electricity societies are in the process of replacing live wild trees and wooden poles with concrete poles by themselves, in their capacity and this process has to be accelerated by giving any government aid if required. Furthermore, in case of grid connection it would be of best interest of all to allow CEB to maintain distribution system which would be maintained up to their standards, while consumer societies only operate generation plants.

Feeder Protection Schemes

Most of the schemes have used Residual Current Devices (RCD's) with adequate current rating, for feeder protection. RCD's for each distribution feeder provides sufficient protection in typical off grid electrification scheme, given that these are in operational condition. However due to lightning surges and other reasons, RCD's get damaged. Furthermore routine testing does not happen in most of these VHS, and people only realize that RCD's had been damaged only when an accident occurs. Especially in a situation where other factors like wayleave clearances are compromised and bare conductors are used instead of insulated wires, maintaining RCD's in operational condition is critical.

Recommendations

It is advisable to make routine inspection and testing of RCD's and over current protection of feeders mandatory by plant operators, and to maintain log book regarding such inspections and observations made. Such method would not only espouse adherence to standard procedures and thereby promote operational discipline among these communities, but also becomes important for decision making in further study as past data regarding accidents and technical faults would be available.

Impact of Lighting Surges and protection

Using bare conductors makes the distribution system and thereby, the generator and equipment at consumer end, vulnerable to the impact of lightning surges. The usual protection provided by DDLO or lightning arrestors at distribution substation is not present in these off grid schemes.

Recommendations

Some schemes have used elementary spark gaps at power house to reduce the impact of lightning surges which had been a successful implementation. All those who have used spark gaps have said that they have experienced a significant reduction of lightning surges and consequent damages. Therefore it is advisable make using spark gaps or any other lightning protection device mandatory at power houses. Furthermore varistors can be used at consumer installations for protection from lightning and other surges. Awareness campaign on using varistors can be conducted for the benefit of consumers in this regard.

Condition of Domestic electrical installations

Condition of Domestic electrical installation varies largely from scheme to scheme. There are some houses that maintain very good standards despite being served by an off grid scheme, while there are many that still carry on very dangerous practices and arrangements in these schemes. Many consumer installations are equipped with RCD’s and MCB’s but hardly test the functionality of those from time to time. Some of these devices were not in operational condition by the time of inspection. Other than that, there were some minor issues associated with standard of domestic wiring, and Earthing arrangements.

Recommendations

Furthermore, it is plausible to assign the task of routine inspection and maintaining wayleave clearances for each section of distribution system and service connection for his installation, to each consumer and report any danger to plant operator and society. This might be an effective way of reducing accidents.

3) Grid connection

When grid connected, these micro hydro schemes broadly falls into the category of distributed generation which is a topic that had been subjected to extensive discussion in technical literature owing to recent developments in power sector. Distributed Generation (DG) represents a new paradigm of analyzing power systems. The conventional idea of a power system was based on large centralized generation and high capacity transmission lines which connect load centers with these generation points. The geographical separation between load and generation was a hard fact back then. However owing to the evolution of production forces which propelled major socio economic changes in last 3 or 4 decades, this separation is not a general hard fact anymore. Exponential demand growth and depletion of energy resources gave rise to demand supply incongruence in energy markets which have compelled research on alternative energy sources. This whole process has espoused Distributed Generation to a great extent. Sources indicate that in Denmark, DG has reached 37% of total energy mix and 40% in Netherlands. Liberalization of power markets too have been an impetus for DG.

Solar PV, Wind turbines, Micro Turbines, reciprocating engines and biomass are globally most popular DG technologies while grid connected Micro hydro schemes of this scale, is limited to some developing countries.

By Distributed Generation, central generating companies can reduce load on their transmission equipment, provide local voltage support, and increase economic benefits. Peak shaving in energy markets where Time of Day tariff is in use, is another popular use of DG especially by large industrial consumers.

3.1) Distributed Generation from power systems perspective

Connection of DG back to the grid or theoretically, Interconnection of DG's is for back wheeling the excess power produced by a DG plant to the grid. There are number of technical barriers associated with interconnection of Distributed Generation plants like stability, protection, power quality, islanding issues and system operation.

Power System stability

The stability question is not something that can be overseen in the process of grid connection. In fact Protection and Stability are two main concerns of CEB and reason for their reluctance to connect these Micro hydro schemes with their system. Most of the synchronous generators used in these DG plants have simple exciter and governor control schemes compared to large central power generators. Induction generators have no control over reactive power at all as they use capacitors of fixed value for excitation and power electronic based systems also does not have large power capabilities due to excessive cost associated with the controller. These problems together with low inertia of these small DG units which can affect damping of the system, can become a significant problem when interconnection takes place.

Number of studies had been carried out in other countries using power system simulators though most of them are carried out for solar, wind or micro turbine based technologies as micro hydro based DG is vastly popular only in 'Developing Countries' like Sri Lanka. Given below are findings of some studies carried out in University of Queensland Asian Institute of Technology, and other universities, under the supervision of Dr Mithulan Nadarajah. [3][4]

Benefits of DG penetration

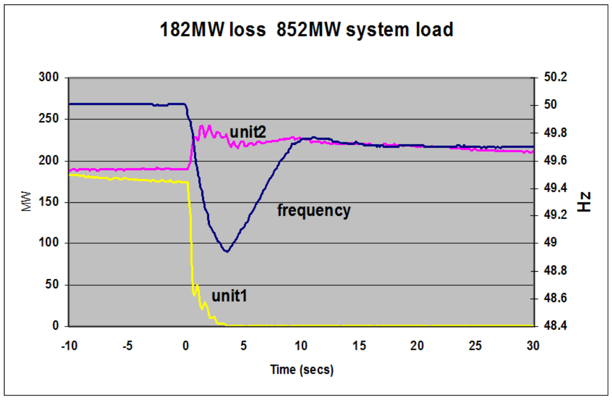
The impact of DG on transient stability of transmission system had been studied using power system simulators. The '*maximum rotor speed deviation'* and '*duration of the oscillations',* had been used as two indicators of transient stability of large synchronous generators. The studies have suggested that the maximum rotor speed deviation for most *synchronous generators* decreases with increased use of DG technologies near them (in the grid). And when used with proper controllers (for frequency and voltage) 'oscillation duration' too tends to decrease with increased DG penetration.

The transient behavior of transmission system under N-1 security criteria had also been investigated in the study. The system had been modeled with different DG technologies like synchronous generators, power electronic controller (inverter) where the centralized generator is acting as the swing bus. When the increased load is covered only by increasing the centralized generation, the indicators '*maximum rotor speed deviation'* and *'oscillation duration'* increases. When the active power output of the centralized generator is gradually decreased and replaced by a combination of different DG technologies, the indicators have decreased. Therefore it's reasonable to suggest that increasing DG penetration will improve the transient stability under single contingency fault scenarios.

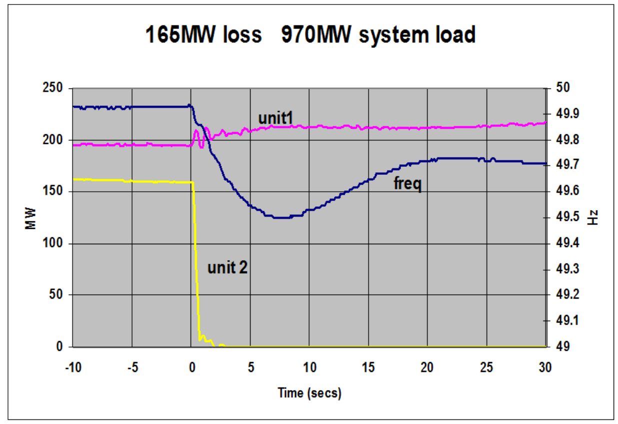
Meanwhile a study on maximum power angle deviation between two synchronous generators under transient fault conditions, suggests that utilization of DG units reduces the magnitude of maximum power-angle deviation. This is very useful characteristic as in severe fault conditions; dire consequences like pole slipping can take place due to power angle deviation.

Stability Issue of low inertia DG penetration.

The connection of many low H-Constant generators to power system can make an adverse impact on system inertia, and therefore can lessen the damping available in the system. Having the optimal level of damping is important in a system for transient stability because it directly affects the rate of change of system frequency as having sufficient damping, (low Q-factor) means more energy is dissipated per cycle of oscillation and system steady state is achieved more quickly.



Low Inertia System



High Inertia System

(Source: Systems role of Generation - Leslie Bryans & Alan Kennedy)

The picture shows that high inertia system is less disturbed by transients. A pendulum suspended in air and a pendulum suspended in viscous oil, are good examples of systems with low inertia and high inertia respectively.

Studies carried out using power system simulators and modal analysis in s-domain, have revealed that utilization of DG in certain way can improve damping ratio. When small number of Distributed Generation units are present near some of the load nodes, the control systems of these small generating units can only have local action and global damping ratio of the system had worsened. However, using large number of DG units which are uniformly dispersed in low voltage area extends the controller action to most of the load nodes and therefore improves the performance of system. Other than that, the simulation also has suggested that large power flows in transmission lines have detrimental effect on damping of oscillations and therefore the reduction of large power flows in transmission lines by DG penetration can be beneficial.

Recommendations

Power system stabilisers (PSS) are used in many European countries to mitigate these adverse effects associated with DG penetration.[5] And after systems studies Sri Lanka can use PSS as required, to enhance stability and damping when connecting of these Induction generator based schemes to CEB system.

Meanwhile using flywheels rated at 10-20MW is burgeoning technology that is popular in USA [6] which they use for the same purpose. The purpose is to enhance system inertia and thereby improve stability.

However, micro hydro schemes in Sri Lanka are likely to be capable delivering more inertia to the system than wind or Solar PV which are rampant in European countries and USA. If system studies suggest that low inertia is a problem, small flywheels (of the scale of automobiles) can be used with system to increase system inertia.

Voltage Stability

Studies have also revealed that the increase of the penetration levels of DGs causes more damping to the voltage in network. Simulations have shown that lower steady state voltage deviations can be achieved at load terminals when DG sources are used near them. However synchronous generators are better in this regard when it comes to voltage regulation because Induction generators tends to adjust their slip and hence reactive power consumption, in transient conditions. Generally it can be said that using DG can significantly improve voltage profiles in long feeders. But there is no experimental evidence on whether Induction generators can make a significant contribution to the transient voltage stability. However it should be noted that this is related to the presence of DG and not necessarily DG penetration. Because with high DG penetration level, that is in a scenario where Centralized generation is substituted by DG, low fault levels of the system, would result in excessive voltage dips when equipments are switched on [7].

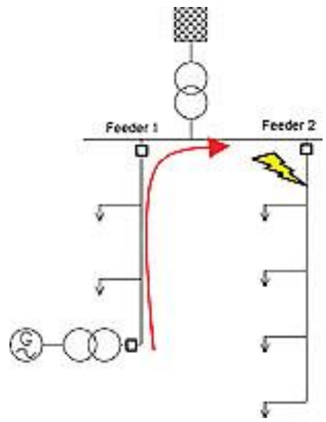
3.2) Protection Issues

Protection is one of the key issues when it comes to interconnection. Power flow in distribution network is usually unidirectional and the protection philosophy in normal power system is based on this. Connection of DG to low voltage feeders violates this which can cause problems.

Sympathetic tripping

Sympathetic tripping which is also known as false tripping is where a healthy feeder trips unnecessarily for a fault on another feeder. Sympathetic tripping can take place due to many reasons and a very common case is where the line charging current of the largest feeder is more than the ground fault pick up current level. It is said that in some occasions even the imbalance of phase to ground capacitances can be sufficient for sympathetic tripping. Generally Relay settings of feeders are deliberately selected after taking these factors into account.

A special case of sympathetic tripping can take place in a feeder to which Distribution Generation is connected, due to a fault which occur in another feeder. In normal scenario, faults in one feeder of the substation will not be felt by another feeder connected to the same bus bar except as a voltage dip of the busbar. But in a situation where distributed generation units are connected to a feeder, DG will act as a source and will contribute to fault current in an event of a fault. (see diagram)



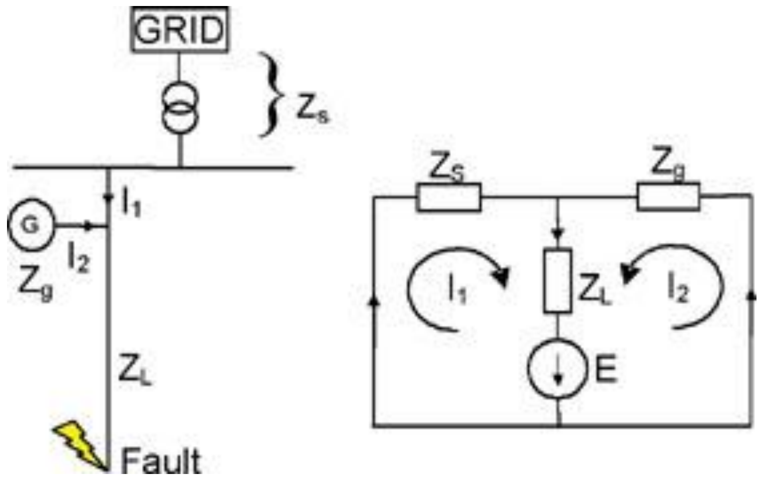
The ratio of current contribution from each source (DG and transformer) will depend on the ratio between their impedances and short circuit current contribution. Sympathetic tripping can be a problem with DG connected to a distribution feeder when two or more radial circuits are fed from a common source, DG with a relatively high short-circuit contribution is installed in a feeder, or if characteristic of Over Current relay at the feeder where DG is connected is faster than Over current relays on parallel feeders.

Recommendations

- Over current relay settings of the network has to be changed as required, to allow faster response of protection devices at the circuit without DG, and slower operation of protection devices at feeders with DG. This has to be done without loosing coordination with any downstream protection devices and hence settings of downstream devices too should be revised.
- Using directional protection to upstream protection devices of the network, to eliminate tripping on current flow reversal.
- Using transfer tripping signals or any such method to get a signal from faulted feeder to healthy feeder to which DG is connected such that it will not respond to irrelevant situation.

Blinding of Protection

In normal radial distribution feeder any fault occur in downstream of substation bus bar is fed only by transformer and hence the entire fault current is fed by substation which passes through protection CT at substation. But in a situation where DG units are connected to distribution feeder, both the transformer and DG unit act as sources and feeds to the fault. The current contribution from DG reduces the current seen by feeder relay and can lead to prevention of operation of over-current relays.



The impact of this phenomena increase with the size of DG unit as it would contribute more to the fault current. Furthermore, the fault current generated from DG in short circuit faults, strongly depends on both generator type and network configuration. Synchronous generators can feed rather large and sustained currents while inverter based systems in most cases, will be controlled so that their output is limited to rated current.

Recommendations

- The pickup current of respective feeder can be reduced accordingly after carefully considering the short circuit current contribution from DG connected to that feeder. But this can again lead to false tripping (sympathetic tripping) due to fault in adjacent feeder. Therefore adjusting the relay settings of adjacent feeders too would be required if we adopt this strategy. However it is likely that this will lead to increase of sensitivity of a significant part of distribution system and can result in nuisance tripping. Since the vulnerability of distribution system to nuisance tripping depends also on operational environment, only practical implementation can verify the success of this method, and therefore will essentially depend on the context.
- Using distance protection for feeders to increase the amount of DG connected to the distribution grid, is another strategy proposed to mitigate this problem. Being a zone protection scheme, distance protection acts more or less independent of the size of the fault current. However distance relay settings too would have to be revised as reduced grid contribution due to current contribution from DG, the impedance calculated to fault location might increase and hence faults which are supposed to be cleared in zone

1 might then be cleared in zone 2 and so on. “The seriousness of this problem depends on local short circuit power, X/R ration of distribution feeder, and size of generator” [8]

Anti-islanding protection

Prospective islanding is a critical safety concern associated with Grid connection of DG. In an event of sudden loss of grid connection due to recloser operation or some permanent fault, part of the network might operate as an island. Islanding is undesirable due to reasons including safety concerns to maintenance personals when de-energized circuits are back fed by DG, and synchronization problems when reclosing take place.

Islanding problem is usually addressed by disconnecting the Distributed Generation Unit from feeder when islanding taking place. However with increasing DG penetration, it had been noticed that disconnection of DG in an event of mains failure would seriously reduce the expected benefits of DGs. The idea of keeping DG connected during system disturbances is being debated upon by researcher throughout the world and various low cost protection schemes are being developed and tested as a result. [12][13]

The conventional method of implementing Anti- islanding protection is to provide ‘Transfer tripping’ with lockout relays. [14] Two way communications by SCADA or any other means, will ensure that ‘Transfer Trip’ signal will be sent to DG facility in event of a fault. This will ensure that DG is not connected and hence that there would be no synchronization problems when feeder Auto-recloser operates. The DG interconnection transformer will be reclosed after about 10sec. For voltage and frequency stabilization and Generator will be resynchronized in 5mins. Lockout relay (86 Device) will lockout generator resynchronization after about 5mins in case of a permanent fault.

However using transfer tripping can be expensive for small DG units like micro hydro plants and Under/Over voltage, Under/Over frequency relays are used instead, to detect islanding. This would only be effective if there is a significant power mismatch in the island, due to islanding operation. U/O Voltage and U/O Frequency relays will fail to recognize the fault if power mismatch of the island is close to zero.

Recommendations

Despite recommended practices even most of the mini hydro schemes in Sri Lanka doesn’t use transfer tripping as it requires communication links to be maintained. In most of such cases U/O voltage and frequency relays do provide adequate protection and the plants had been in operation without serious problems.

Since we are using Induction generators it is advisable to reduce the reactive power compensation at the IG when it comes to grid connection, such that part of their reactive power requirement is provided by grid. This would ensure that generator will lose its excitation due to reactive power imbalance, and U/O voltage relay will operate.

Nuisance tripping

Nuisance tripping can also be a problem with increased DG penetration as the short circuit levels increases as DG interconnection takes place. In normal operation, protection devices are coordinated such that the primary protection operates before the backup can take action. But with the increased short circuit levels, uncoordinated situations may be found where the backup protection operates before the primary, which results in nuisance tripping to some of the loads. Furthermore, power surges from cycling loads in local system can be detected by U/O Voltage and frequency relays as islanding scenario which too can give rise to nuisance tripping.

Finalizing relay settings should be done considering all these aspects and is best done practically when commissioning and can vary for each DG scheme.

3.3) Power quality concerns

Other than protection issues discussed above, there are some power quality issues associated with Distributed Generations.

Voltage regulation: Voltage regulation can be a problem in feeder with DG due to reverse power flows. If the downstream DG output exceeds the downstream feeder load, there would be an increase in feeder voltage with increasing distance. If the voltage at substation end of the feeder is somewhere near maximum allowable value, voltages downstream of the feeder might exceed acceptable limits.

DC current injection: There is a potential of DC current injection when DG power converters are directly connected to substation feeder without isolation transformers. This can make serious impact on transformers and other magnetic elements, and can result in torque ripple in machine loads nearby. Therefore using isolation transformers wherever possible is recommended.

Unbalanced Grid: connection to unbalanced grid can be a problem for rotating machines as well as DG based on PWM inverter technologies. Because the DG is maintained and controlled as balanced source, the product of positive sequence and negative sequence component can cause a power ripple of twice the frequency and also can result in harmonics in inverter output current.

3.4) IEEE1547 interconnection standards

Interconnection standards IEEE 1547 were developed to provide a uniform standard for interconnection of distributed generation. Maintaining overall stability, safety and cost became critical as DG penetration levels increased in recent past and technical standard was imperative in this regard as, lack of standard with increased DG penetration would otherwise result in problems.

The standard mainly comprise of following sections though there are 8 sections altogether.

- **IEEE Std 1547.1 (2005) Standard for Conformance Tests Procedures for Equipment** – this specifies the type, production, and commissioning tests that shall be performed to demonstrate that inter connection functions and equipment of a distributed resource conform to standard. The test procedures must provide repeatable results independent of test locations, and flexibility to accommodate variety of technologies.
- **IEEE Std 1547.2 (2008) Application Guide for IEEE 1547**– Provides technical Background and application details to support the understanding of standard. This characterizes various forms of DG and specific interconnection issues associated with, and includes technical descriptions and schematics and examples
- **IEEE Std 1547.3 (2007) Guide for Monitoring Information Exchange and control** – this guides the information exchange and control techniques and describes functionality, parameters and methodology for foregoing.
- **IEEE Std 1547.4 (2011) Draft Guide for Design, Operation and integration of Island Systems** - this mainly addresses engineering concerns of DG island systems, and is relevant to the design, operation and integration of those.

(Source: Tom Basso, IEEE 1547 Interconnection Standards (Standard for Interconnecting Distributed Resources With the Electric Power SystemIEEE PES Meeting June 9, 2004)

IEEE 1547 is a newly developed standard of which some parts are still being refined in various Work Groups. Since Grid connection of our village small hydro schemes is a long term project and is likely to be a non temporary one, it is recommended to do a study on IEEE 1547 for adoptability of it to specific conditions in Sri Lankan context in order to ensure long term sustainability and compliance to international best practices, in technical domain.

4) Socio-economic aspects

The contribution from off grid small hydro schemes to empower rural community is critical from macroeconomic perspective. Grid connected micro hydro scheme can serve as source of revenue to these societies and even despite grid connection, the consequent improvement of the quality of life of these communities will be reflected in Human Development Index (HDI). Access to electricity opens new avenues to rural communities for small scale industries and therefore ultimately contributes to rural economic development.

Meanwhile rural electrification also causes a saving of kerosene subsidy to government due to replacement of kerosene lamps used for lightning. A study conducted by scholars from University of Ruhuna has revealed that average kerosene consumption of a household is 0.7L/month [16] while 500000 households in Sri Lanka are un-electrified according to rough calculations of MOPE. [17] This suggests that kerosene consumption of un-electrified households amounts to approximately 3431.4 MT/year which according to 2007 central bank report is about 2.04% of total kerosene consumption of Sri Lanka. Hence it can be said that savings from kerosene subsidy due to rural electrification is material from government's perspective.

But again the marginal cost of energy has to be considered since Sri Lankan power sector is still a form of oligopoly where prices doesn't reflect the true cost of energy when it comes to electricity and chances are such that people might be using electricity in lieu of any other energy source for a given task, because of low cost of electricity as prices doesn't reflect true economic cost of electricity to the country. However due to the low per unit cost of micro hydro schemes, marginal cost of energy would still be low despite the energy market not being governed by true market dynamics.

As per MOPE, the estimated total cost of connecting additional consumer for national grid to achieve 100% electrification is around 200,000 LKR, which include costs of generation and transmission expansion projects, and deployment of distribution network. Using these existing off grid electrification schemes and developing them upto CEB standards can effectively reduce that cost from government's perspective.

It is possible for government to utilize finances used for kerosene subsidy to enhance quality and standards of these village hydro schemes.

Losses and underutilization of Energy resources

Underutilization of hydro resources due to limited finances is a significant factor in micro hydro development in Sri Lanka. Usually due to financial constraints, developers tend to settle for power plant of lower generating capacity even when hydro potential of the site is much more. This ultimately results in economic disadvantage to the country that has to be avoided.

Furthermore, energy losses due to poor quality fittings and structures, ultimately results in non optimal utilization of resources in economic domain. Not conducting proper hydrological studies can result in high civil engineering cost for low pressure tunnel, weir and penstock without deriving maximum hydro potential of the site.

Penstock design which causes high head loss, inefficiencies due to shaft eccentricity, friction due to low quality bearings and other losses associated with mechanical coupling and sub-optimal designs are significant components of total losses. Generally non electrical inefficiencies from the potential energy at forebay tank upto generator airgap, amounts to a significant value. Low efficiency Induction machines, power loss in ballast load are electrical losses that have to be taken into account. Losses in Distribution system will depend on the length of low voltage feeders and their geographical span, which are related with voltage regulation of feeders.

Meanwhile limited hydro power potential and seasonal variations of flows in waterways due to rain falls imposes limitations on maximum demand in these schemes which causes load shading programmes. This has caused debate in some consumer societies and measures taken to control load like television during peak hours has been particularly unpopular.

Effective DSM technologies can address this problem to a certain extent even at this level. Using White LED lightning and LCD televisions which are technologies becoming affordable, can provide a solution for this problem of limited generation capacity. Many burgeoning refrigeration technologies too can derive significant amount of energy savings. In parallel with grid connection and enhancing the technical standards of these off grid schemes, a Demand Side Management programme can be launched with adequate funds, in order to make these new technologies popular and promote a culture of early adopters from which Sri Lanka can benefit greatly to mitigate the energy crisis.

Load curve variations utilization patters

Mainly the load served by these power plants is lighting load which exist only during night time and low utilization of energy during daytime results in significant waste of energy in dump loads.

One economical viable and technically feasible option, as it had been suggested earlier in this report, is to introduce a load like grain mill or saw mill to generator shaft, directly or via a mechanical clutch to make use of that energy for productive purpose. Another option is to inject this excess power to grid after an event of grid connection. But proper study on this subject would require load flow studies and system modeling.

Need of System Studies

Lack of systems studies for new scenario, can be an impediment for future decision making and also to tackle day time low usage issue. System modeling and load flow studies using induction generators particularly introduces new challenges. Most of the distributed generation of this scale is based on inverter technology or synchronous generator model and IEEE 1547 Interconnection standard too does elaborate mostly on such technologies. Voltage and frequency regulation requirements of plant can hence be achieved as per standard in inverter based plant. But using Induction generator introduces new challenges when system modeling. Adopting governor models and generator models, whether to provide room for different load set points, whether total feeder would act as generator bus injecting power to substation, becomes technical problems that has to be resolved.

Despite control strategy, energy dissipated through dump loads should be minimized in an event of grid connection, to maximize efficiency. But absence of natural synchronism and resultant frequency and voltage regulation in Induction generator can give rise to issues when it comes to controlling power flow.

Extensive studies had been carried out on DG, steady state and transient stability of them and total impact of DG penetration on national electricity grid in various countries. Unfortunately most of them are on technologies like wind, solar, or biomass. High inertia and good damping characterizes micro hydro especially when comparing solar PV or wind and systems studies should be carried out for this too. Calculation or estimation of fault levels is critical for providing protection which again demands further systems studies.

Pertaining issues in Village Hydro Schemes

During the study it had been observed that most of the power plants though are aided by RERED project and have received technical expertise from organizations like ENCO, REDCO and 'Practical Action', fails to sustain the standards they upheld at the beginning. Weediyawatta village hydro scheme is a good example for this which had started like 10years ago, and had served as an exemplar model of an off grid electrification scheme, has now fallen into mediocrity.

Financial situation

Most of these village hydro schemes do not have bulky bank accounts mainly due to the fact that they have to repay loans taken under RERED project. In fact some of these co-operative societies are in serious financial difficulties and are even short of money required to do urgent repairs and maintenance of the power plant. But proper financial management and transparent procedures are very likely to rectify these issues as hydro power generation irrespective of the scale, is one of the cheapest sources of energy (not considering environmental concerns, water management and associated opportunity cost)

No financial statements or comprehensive records of expenses incurred and revenue collected, were available in Micro Hydro schemes which we have inspected. Operational and maintenance overheads of these Power plants are not in a difficult to manage level. Wages or allowances for plant operator and cost of repairing and maintenance of the plant are two main cost components of these power plants. The cost of replacing damaged Circuit breakers, replacing bearings and water seals, and repairs of the generator itself are main elements of the latter. These together does not sums up to a huge expenditure and a proper revenue collection mechanism together with transparent procedures should be able mitigate the financial difficulties. Though it would not be reasonably practicable for small Electricity co-operative society to maintain a database on energy generated and comprehensive set of accounts and financial statements, properly maintaining the records of basic income and expenditure is plausible goal to achieve. Such system will be quite useful in making investment decisions to further develop the power plants. Say if records throughout few years suggest that low quality components (bearings, circuit breakers, or control circuits) results in recurrent expenditure as well as interruptions, they can opt to invest on better quality substitutes, after cost benefit analysis. People of these societies should be educated in this regard and raise awareness about benefits of standard procedures and maintaining records.

Management and Operational procedures

Analysis of the situation reveals that lack of proper management procedures and reporting mechanisms, failing to adopt technical best practices in sustainable way, and disputes within these societies have become hindrances for their sustainable progress. Most of the societies are not adequately equipped with knowledge and skills required to effectively control and regulate the activities and often tend to forget about the power plant as far as there are no power failures. Vast majority of the power plants do not have a full time attention of an operator due to financial difficulties. In most cases there are one or two personals who attend to repairs when there is a fault or breakdown and the plant runs its own as far as there are no power failures.

However there were few electricity co-operatives which were exceptions to this description. Sirioya Janashakthi micro hydro scheme is an example of such scheme where there is a permanent plant operator in the premises, presence of sub standard constructions is minimal, and has also had been able to maintain about 200thousand LKR in bank after incurring all operational and maintenance costs. However this is due to the presence of few people with integrity and discipline.

Meanwhile some societies had their own disputes among members regarding decisions, together with uncooperative behavior of some individuals who attempts to sabotage the power scheme. Some individuals were said to avoid volunteering in events organized by the society and some were reported of not supporting the load shading decisions taken by the society and also attempting to sabotage such attempts by deliberately creating earth faults in feeders.

Furthermore, Ethnic and political divisions in the community, (if there are any) can make an adverse impact on the proper functioning of the society. (eg. Kushadevi Micro hydro project in Nepal) Especially if there are conspicuous divisions in the village based on wealth, race, religion, or any other basis, special measures should be taken to ensure that any discrimination based on such factors will be avoided.

Recommendations

In this context it is imperative to emphasis the importance of establishing proper legal and administrative framework in this scale, which can ensure that Seven factors of non-decline taught by Buddha to Vajji’s that are, regular assembly, concordant assembly, reasonable rules, respect for others, objectivity and non attachment, peaceful atmosphere, and mindfulness, would be enshrined in all these societies. For this target, we suggest to implement,

- ***Accounting*** for expenses incurred and revenue collected to be made mandatory – accounting needs not to be comprehensive, yet at least basic details of income and expenditure has to be recorded.
- A mechanism to ensure that prepared accounts are being ***periodically reviewed*** by Divisional Secretariats, Sustainable Energy Authority or PUCSL. It would be prudent to avoid Local Governments for good as that would create a loophole in the system from which politics can creep in and destroy community based cooperatives. The records of accounts can to be submitted annually to PUCSL, SEA or Divisional Secretariat.
- To further aid this system, PUCSL can ***develop a format to be used for financial accounts*** and record keeping which can be a set of forms. Such format can clearly state which aggregate cost components they should report about, and a consistent format of reporting can be a great convenience for any analysis for future decision making. This shall not be a bulky set of forms asking for comprehensive set of data, and shall be simple 2 or 3 forms which can be submitted to PUCSL annually.
- Federation of Electricity Consumer Societies (FECS) to be empowered to monitor and audit the entire process and ensure transparency and best practices.
- ***Training programmes*** to be carried out for training one or two representatives from each society to equip them with technical knowledge and skills required for effective running of the power plants, and most importantly, to keep communication channels alive with a technical resource pool (say pucsl or SEA) via FECS such that technical problems faced by these societies will be addressed in timely manner while PUCSL will be kept updated on the latest status of these exempted power plants. Furthermore, this can be used to keep Societies updated about new developments in technical and safety standards.
- For good governance and proper administration, PUCSL can propose a draft constitution for Electricity Consumer Societies after studying existing constitutions of these societies. Currently most of these Societies have such document which dictates rules and regulations applicable to members and what would be the applicable fines in different cases. Though there are some very good societies which are efficiently managed and administered, we cannot expect a utopian civil society to be forged and maintained. Therefore it’s efficient and effective regulatory measures that can ensure proper functioning of these electricity cooperatives. And studying how good set of rules and regulations had been beneficial for administration of societies is imperative in this regard as any proper regulatory measures should be based on objective facts, than

concepts. Hard facts discussed above like prospective discrimination, measures to minimize un-cooperative behavior, have to be taken into account in this process.

Above steps will firmly establish two lines of reporting (One for administrative and financial auditing and one for technical assistance) between these isolated societies and authorities. Both can be facilitated by FECS which can evolve into much bigger organization which can effectively coordinate all these activities.

The relationship between transparency and best practices, and technical standards and long term sustainability of village hydro schemes is quite analogous to base-superstructure relationship discussed in cultural theory. Proper administration, financial transparency and legal framework to ensure that, is the base on which the superstructure of technical quality, compliance to safety standards and quality of supply is made. Therefore trying to build the latter (superstructure) without concerning about former (base) would be futile.

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