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Network integration of distributed power generation

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Abstract

The world-wide move to deregulation of the electricity and other energy markets, concerns about the environment, and advances in renewable and high efficiency technologies has led to major emphasis being placed on the use of small power generation units in a variety of forms. The paper reviews the position of distributed generation (DG, as these small units are called in comparison with central power plants) with respect to the installation and interconnection of such units with the classical grid infrastructure. In particular, the status of technical standards both in Europe and USA, possible ways to improve the interconnection situation, and also the need for decisions that provide a satisfactory position for the network operator (who remains responsible for the grid, its operation, maintenance and investment plans) are addressed.

Keywords: Distributed generation; Regulations; Interconnection; Protection; Metering; Network planning

1. Introduction

Distributed power generation or simply distributed generation (DG), is in the focal point when it comes to providing possible solutions for a number of socio-economic energy problems that have taken on considerable importance as we move into the new millennium. The enhanced efficiency, environmental friendliness, flexibility and scalability of the emerging technologies involved in distributed generation have put these systems at the forefront of solutions to provide power generation for the future.

Moving away from the classical "standby" image of small generator sets and battery based UPS, the use of DG is expected to grow through a wide range of applications [1]. In many parts of the world, where there is no power grid, DG can be the only source of power. On the other hand, in regions well provided with power supply networks, there are few who contemplate totally replacing connection to the grid by complete reliance on DG, and it is this aspect of integration of DG into the network that has led to a number of issues which need to be resolved, and which will be highlighted in the paper. The issues involve, not only technical aspects of introducing DG as a power source in the network, but also safety and financial concerns of the utility companies, and inherently, the costs of installing DG with connections to the grid.

The development of the electrical network over the past century has been dominated by the concept that very large power plants in places of strategic geographic relevance, with respect to primary energy resources and safety, provide the optimal cost-effective generation of electricity. Coupled with this, electrical networks have been developed to transport the electrical energy from the source to the end-user in the most effective manner using a hierarchical structure of high voltage transmission networks, medium voltage distribution networks and low voltage "last mile" networks. To ensure, in this regime, both a very high security and availability, the networks have been in many instances meshed, to provide alternative routing in case of faults, and are protected from critical failures and natural phenomena, such as lightning strikes, with mechanical and more recently advanced electronic protection schemes.

In the strictly regulated situation, the large, monolithic, public utilities could plan from conception to completion for the introduction of new plant including not only power plants, but also the auxiliary infrastructure needed to connect the generation to the grid (i.e. sub-stations, rights-of-way, transmission lines and the injection into the distribution network). The networks, built up over the years under this regime, are thus characterised by the typical design features of this power flow from a relatively small number of large power plants feeding a very large number of dispersed end-users.

With the trend to deregulation of the energy markets, traditional utilities have in many cases been restructured and

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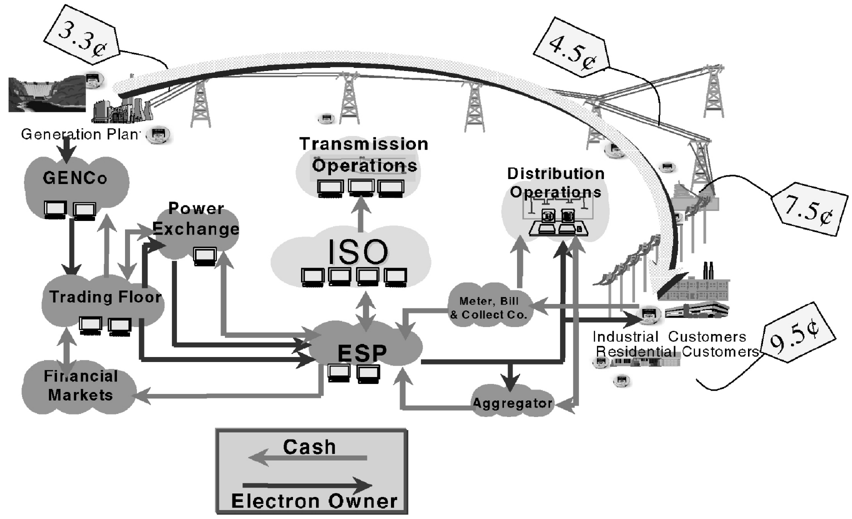

Fig. 1. With deregulation, the trade in energy paves the way for independent generators and thus also DG.

privatised, in which case they now also have a commitment to shareholders (Fig. 1). Furthermore, the networks have been ''opened'' to allow new energy suppliers to connect to the grid. Generally, the emerging new suppliers have installed large power plants, which have involved large capital investments, in-depth planning, and connection to the high voltage transmission grid. Thus, although this represents a very new situation as far as the plant ownership, and energy trading is concerned, the plant has been introduced into the network environment within the classical framework.

2. Classification of distributed generation

Against this background of the development of the power network and deregulation, the term ''distributed generation'' has been used to describe a number of different generation scenarios that cannot be simply classified in the structure mentioned previously. Characteristically, DG is a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW) that is not a part of a large central power source and is located close to the load. DG includes biomass based generators, combustion turbines, concentrating solar power and photo-voltaic (PV) systems, fuel cells, wind turbines, micro-turbines, engines/generator sets, small hydro plants, and storage technologies. These can either be grid connected or operate independently of the grid. Those connected to the grid are typically interfaced at the distribution system, and thus dispersed across the utility's electric network rather than concentrated in a single location.

Typical of the broad classification of DG is that when in 1997, the newly formed International Conference on Electricity Distribution (CIRED) Working Group on distributed generation posed the question to the member countries of CIRED: ''What is your definition of dispersed or embedded generation?'', there was no clear consensus, but rather a number of different classifications, some using voltage level, some using nearness to customer load, while others used primary mover or dispatch situations [2]. The International Council on Large Electric Systems (CIGRE) Working Group has set its definition of DG to be generation that is:

- not centrally planned;
- not centrally dispatched;
- usually connected to the distribution network;
- smaller than 50–100 MW.

Another definition, adopted by the Institute of Electrical and Electronics Engineers Inc. (IEEE), is that DG is: ''The generation of electricity by facilities sufficiently smaller than central generating plants as to allow interconnection at nearly any point in a power system. A subset of distributed resources''.

Needless to say, these definitions, imply a very wide range of different possible generation schemes. At one end of the spectrum, there are large industrial site generating plants rated at many tens of MW capacity, usually combined with provision of steam, hot water, etc. in typical high efficiency combined heat and power (CHP) configurations, while at the other end, there are small units of a few kW, typical of domestic DG installation.

In general, the interesting aspects of network integration relate less to the very large industrial sited DG units, and those which are installed directly by utilities to support their networks, but more to the medium and small-sized units relevant to a large segment of the commercial and industrial sector, as well as residential sites, since it is in these segments that a large number of units may be involved. There is a very simple reason for this. Integration of the larger plants necessarily involves planning and engineering of the complete installation. The cost of the installation will include grid connection, possible grid reinforcement and the requirements of adherence to power quality conditions of the network.

On the other hand, the ability to achieve large scale deployment of DG relies on the interconnection to the grid being safe, non-disruptive and economical particularly when applied to smaller units. Whereas the first two items relate strongly to the way the units are technically embedded in the network, the economical issue relates both to the cost of technology, the regulations to be fulfilled by the interconnection, and the effects on the utility pricing structure.

3. Distributed generation—the benefits

DG installation has a long history, both in USA and Europe. Presently, the variety of benefits to consumers, energy service companies, and distribution grid operators with grid connected and on-site power systems is evolving rapidly with deregulation. The specific benefits depend on the local conditions and installation owners interests (Fig. 2). Thus, reasons for installing DG include:

- combined heat and power plants—high efficiency;
- standby/emergency generation—enhanced reliability;
- peak shaving—using DG as a cost-effective source of peak demand power, or economic savings in energy consumed from utility (US$/kWh) and electricity demand (US$/kW) charges;
- grid support—reduction in grid losses, typically saving 10–15%, provide voltage support, and power factor correction;
- grid investment deferment—install DG instead of network extensions/upgrades;
- green power—renewables are well placed as DG plants, being often subsidised;
- premium power—ensure high quality supply for specific 24/7 services.

CATEGORY	POTENTIAL
Substation Deferral	$1.60 - $60.27 / MWh
Transmission System Losses	$2.34 - $3.14 / MWh
Transmission Wheeling	$2.78 - $7.14 / MWh
Distribution Feeders	$0.67 - $1.72 / MWh
SO_2 Emission Offset	$1.50 - $4.50 / MWh
NOx Emissions avoided control costs or emissions offset	$1.15 – 28.40 / MWh
CO_2 Emissions, potential tax offset	$0.00 - $15.00 / MWh

Fig. 2. Examples of potential cost savings with DG installation in a typical US setting.

Furthermore, DG units in mass production do not burden the user with excessive investment or expensive service contracts. They require little maintenance and are usually installed with remote monitoring to optimise service costs.

It has been estimated that there is around 60,000 MW of reciprocating engines and small gas turbines installed in USA [3], predominantly for backup and standby supply, while a recent survey of various installations in Europe (Fig. 3) shows the extent of co-generation as the major source of DG installation and reflects the differences in US and European situation. In particular, the benefits coming from installing DG because of price volatility or quality of supply play little role in central Europe, the main driver being thermal demand and high efficiency. Strong growth of DG installations are forecast during the next 10–20 years. For example, driven by environmental considerations, the targets for alternative, renewable power generation in Europe are ambitious. According to [4], the renewable electricity contribution in 2010 range from 9.3% for UK and 10.3% for Germany up to values of 21.5% for Portugal or 29.0% for Denmark (all values excluding large hydro). Incentive programs have been launched to support DG, not only for the well publicised wind technologies, but also for example PV installations [5].

In USA, where due to a number of reasons, electricity price stability and supply reliability have been difficult to maintain in some areas, a number of examples show how consumers have been using DG to support their businesses [6]:

- A bank installed a fuel cell to avoid power disturbances that were shutting down its computer systems—the purchase was about the cost of a 1 h outage.

	Installed Distribution Generation MW							
Country	Diesel / GT.	Cogen	Wind	Steam	Hydro	PV	Other	Total DG
Austria		70	13.3		616	0.7		700
Belgium		1426	9.4		98		311	1843
Denmark	36	1811	2411	50	10	0.2	222	4540
France	610	435	8		450		250	1753
Germany		2800	1545		3333	17	904	8599
Italy	492	766	34		2159	5	252	3708
Netherlands		4736	427		37		80	5280
Norway		228	13		909			1150
Poland		3000			2008			5008
Portugal		1140	100		200		82	1522
Spain		4522	1890		1362	1.26	426	8201
Switzerland		408	3			11	363	785
UK		4239	409		1475	1.2	643	6767

Fig. 3. Capacity of DG installations in a sample of European countries as collected by CIRED WG04. Varying local definitions distort individual comparisons, but the trends are clear.

- A large grocery store chain estimates that on-site generation is worth from US$ 50,000 to US$ 80,000 per day when the store remains open during outages and the competition closes.
- A restaurant in Chicago, using a natural gas-fired microturbine, cuts US$ 1500 off its monthly power bill while improving power reliability.
- A police station installed a fuel cell, saving US$ 200,000 over the cost of a line upgrade.

4. Distributed generation and the network—the issues

At present, most utilities have little practice with large numbers of DG interconnections and few effective procedures are in place to understand the effects of DG on the utility system, to process an interconnection request efficiently and complete the interconnection. The issues that arise with the use of DG focus mainly on the concerns of the utilities with DG interconnection. A DG unit inappropriately connected to the grid, could compromise the operational reliability of the distribution and transmission grid or cause injury to utility personnel. Furthermore, as DG installations become more numerous, the utility must be aware of the effect of the total number of DG installations, and this can imply network and/or protection adaptation prior to the $(n+1)$th installation, which leads to questions about the distribution of the costs of adaptation. Other issues which arise involve the metering aspects of the DG installation, and how the owner is reimbursed for energy supplied to the grid.

The typical issues confronting the user of DG when seeking interconnection with the utility grid involve both technical and financial (both user and utility) aspects:

- islanding;
- voltage regulation;
- harmonics;
- reverse (in comparison with the normal network expectations) power flow effects;
- over-voltage conditions;
- metering;
- system losses.

Overcoming such issues relies on interconnection standards and application processing regulations that support mass installation. However, while interconnection standards mainly address technical issues, they are built upon explicit policy decisions including:

- the maximum size of a qualified DG unit;
- whether the utility is allowed to own or operate a DG unit;
- whether the DG owner should carry liability for utility stranded costs;
- how the owner is paid for excess production and open access transmission for generation interconnecting to the distribution grid.

These policy decisions have as much influence upon the mass market for DG as the technical requirements.

4.1. Interconnection technology

Interconnection involves connecting DG units to the grid without negatively impacting safety, reliability and quality of supply. The basis of all interconnection considerations arise from the fact that distribution networks were not created to support DG. The grid is currently designed in a top down manner with defined power flows. Power can usually flow bi-directionally within a certain voltage level (depending on topology), but unidirectional from higher voltage levels to lower voltage levels. It is on this premise also that network protection schemes are defined [7,8]. A large number of DG installations in the LV grid can violate this premise. In this case, power may flow into the LV grid, and as an aggregate be fed back to the MV network. This change in the power flow requires different protection schemes at both voltage levels. The new protection schemes need to allow for reverse power flow while assuring tripping in case of a fault on the MV side.

The interconnection is further impacted through aspects of the network topology. Meshed distribution networks have a higher short circuit power than their radial network (station to station) counterparts. The advantage of meshed networks is a relatively balanced voltage profile and high reliability through redundancy. In the radial network case, the LV is fed by a dedicated MV/LV transformer and are relatively simple to design. However, in this case, the voltage profile is more vulnerable to load steps which implies that DG (above a certain power rating) usually has a higher impact on the voltage profile in these configurations. Other implications can arise from the physical characteristics of the network, whether underground cables or overhead lines are involved, what distances are being covered in the network, and whether the LV is protected by fuses or relays and circuit breakers, as may be the case with industrial site installations [9].

4.2. Simulations on real networks—the effects of DG

To better understand the various situations that may arise as DG units are installed and interconnected to the LV network, a number of network simulations have been carried out using the ABB CALPOS network analysis package (see also [10]). To obtain authenticity, in a complex network environment, a typical German urban model was used, with real network data (topology, transformers, lines, etc.). Just as in a real world situation, a number of model DG units were connected at random to various locations. Different sizes and types of DG were used (50–1500 kW, synchronous generator type and inverter type DG) along with two different network topologies. Both a meshed LV grid with three redundant MV lines, and the same grid supplied on a station to station basis (achieved by opening the connectors between the different segments) were studied. In the station to station topology, there was no connection between different transformers on the low voltage level.

In both cases, load profiles with a maximum power consumption of 5 MV A were assumed (corresponding to the real consumption of the considered grid), and a DG generation profile with a maximum power generation of 7 MV A was applied. The effect of the introduced DG on the electrical parameters of the network was then determined using standard short circuit and load flow techniques.

As with all system studies, there are some specific issues which cannot be extrapolated to all scenarios. Nevertheless, a number of major results, evaluating the situation with typical DG interconnection issues, can be derived from the studies and are summarised hereafter:

1. The effect of DG on the distribution network is largely dependent on the power flow into the network.
   - If the aggregated generated power is smaller than the consumed power in the grid, the changes in the voltage profile are acceptable.
   - A very large power generation in time of low consumption in the grid will usually violate voltage profile constraints. This may require a network reconfiguration or generation limitations.
   - Only when the generated power is significantly smaller than the grid load, can a "plug and power" scheme be applied.
   - The voltage rise caused by a single unit is a function of DG power and short circuit power of the grid at the point of interconnection. Larger single units may violate the voltage profile or constraints of maximum voltage rise even if the aggregated power in the grid is low.
   - The short circuit power in the grid rises because of the DG short circuit current contribution. This may result in unacceptable short circuit levels in some cases (especially when placing synchronous generators on meshed low voltage grids).
   - Connecting lines in the LV grid may overload due to changed power flows.
   - The selectivity both on LV and MV is affected. This has to be evaluated when siting DG. Settings in distance relays, over-current relays, short circuit current indicators, etc. may have to be changed. Additional fuses on the LV level may have to be added to insure selectivity.
   - Reverse power relays in meshed systems may have to be replaced, these may trip under normal working conditions when DG on LV are delivering power to the MV level.
2. Losses in the distribution network are reduced by the implementation of DG.
   - The reactive power in the LV grid depends on the type of DG installed. For DG units with power electronics, any power factor can be chosen and thus, a positive impact of DG on the voltage profile can be achieved. Losses can be minimised through avoiding the flow of reactive power over larger distances.
3. Network reliability can be affected.
   - Network reliability can be compromised if the grid supply is very reliable. DG may decrease the overall reliability by adding internal failures.
   - On the contrary, if the network is not very reliable, reliability can be increased in two ways. DG will support the grid and may prevent blackouts in times of supply shortages. DG may also facilitate islanding when the grid fails and thus increase reliability of the local supply.

The study has shown that interconnection of DG on the LV grid at the same power level as the load is feasible. With generation set below the full load requirement, the introduction is generally not critical. However, in more critical situations, attention has to be paid to protection design and parameter setting, as well as a siting of the DG to ensure electrical parameter limits of the grid (voltage profile, loading of lines, etc.) are not violated.

4.3. Improving the position of DG interconnection

Studies such as the above can provide insight into providing methods and technologies which can facilitate the interconnection of DG on the LV network. A number of simple rules (based on DG power and grid configuration) can determine the needed level of planning. Even for the installation of a lot of aggregated DG power, where planning is necessary, tools can be used with optimisation modules to reduce the planning effort. Parameters such as transformer tap settings, separation points in radial operated MV networks, operational power factors of DG, etc. can be optimised automatically, and reduce the initial cost of installation. Network design changes or reinforcement of weak equipment can usually be identified in one planning session rather than on an ad hoc basis as each individual unit is introduced. Furthermore, applying a probabilistic approach to the analysis of faults and reliability related to the interconnection of DG can show that implementations can be cost-effective, when emphasising the probability of different possible faults and their consequences and applying effective risk management [11], rather than dealing with every possible fault.

As recommendations for interconnection become uniform, the local protection and control of the DG unit can also be improved to support the operational behaviour of DG on the grid. Modern cost-effective control units can provide enough performance to include protection for the DG and the interface to the network. Furthermore, unacceptable levels of voltage rise can be removed by implementing ramping algorithms in the controller and removing the instant on/off effects.

Investments in remote DG control as part of the network operation would solve a number of issues and in many cases may be more cost-effective than new network equipment installation. Generation can be co-ordinated better with the load demand reducing negative impacts on the network. At the same time, ancillary services (e.g. reactive power delivery, active harmonic filtering, P/f control, etc.) can be supplied as a by-product [12]. A scheme with a central remote control can also include other key components in the grid (circuit breakers, electrical power conditioners, storage devices, etc.) enabling an optimised operation of the network (according to the current state of the grid and DG). Applying predictive algorithms would lead to a "proactive control" approach further improving the performance of the network [11].

4.4. Regulations and standards

The present situation with respect to regulations and standards is such that there is no well defined universal standard provided to govern interconnection. In fact, studies of the European [13], and USA [14] interconnection regulations carried out during the last year concluded that regulations were governed on a country (Europe) or state (USA) basis, that some regions had no specific regulations, and that often the regulation was classed as a recommendation with the responsibility on the local utility to provide the interconnection conditions. Although there are standards, committees at work on both sides of the Atlantic, which intend to provide a basis for implementing a set of consistent system technologies, the possibility for a manufacturer to standardise packages, and thus reduce production costs and integration costs to a minimum are very limited, until these are ratified. A brief review of some of the important results provide an indication of the position today.

In Europe there are no common guidelines for the connection of DG units to the utility grids. Effective in most countries is that the rules for connecting independent power generators to the grid are defined individually by the local utility. In some countries there are nation-wide guidelines (e.g. in Germany, the VdEW guideline [15]) which serve as a framework and are only slightly modified to conform to the needs of the local utility. In other countries, recommendations (e.g. in the United Kingdom [16]) provide information for the interconnection. Where possible, previously developed standards are used to partially provide interconnection standards. Typical of these are the use of standards related to connection of loads, harmonics and EMC, or particular DG sources such as PV [17–20].

The main technical aspects (which have been studied in depth [13]), dealing with the interconnection of a DG unit to the LV grid are the following:

- limitation of generation capacity per consumer;
- possible problems related to reverse power flow;
- requirements for independent facilities producing electricity (power factor, harmonics, protective devices, etc.);
- safety and wiring of dc side (possible islanding: crucial issue);
- authorisation procedure.

The guidelines for interconnecting DG units are generally based on the following objectives:

- The operation of the interconnected generator should not pose unreasonable safety hazards (to utility equipment or human beings).
- The operation of the interconnected generator should not degrade the quality of power or the reliability of the utility service.
- The injection of power into the utility system should not cause voltage excursion resulting in out-of-range feeder voltage conditions, voltage flicker, etc.

A similar situation is found in USA. Of the 50 states plus DC, only nine (TX, NY, CA, NH, VT, WA, ME, IN, and IL) are known at this time to have their regulatory authorities considering DG interconnection regulations and rules:

- TX: The Public Utilities Commission has developed the most comprehensive rules in USA. Many specific issues are not addressed in the rules and are delegated to the host utility to decide. The resulting rules are however considered by many as positive to DG interconnection [21].
- CA: The Energy Commission has defined recommendations, based on discussions with Californian electrical corporations. With minor revisions, they are in the hands of the California Public Utility Commission for final approval [22].
- NY: The Public Utilities Commission has developed rules for DG of ratings 300 kV A or less and only applicable for running in parallel with the utility network [23].
- NH: The Public Utility Commission of the state has proposed rules for interconnections; initial draft was in 11 May 2000 [24].
- VT: To date, the department of public services guidelines are advisory only and have not been adopted by the public service board as a state standard [25].
- ME: The Public Utilities Commission decided to undertake an examination of the issues related to interconnection. Recommendations and findings to be reported no later than 1 October 2001 [26].
- IL: The Commerce Commission started a procedure for filing comments about DG related issues. A series of meetings provided recommendations to decide whether establishment of rules and polices by the commission is needed or not [27].
- IN: Interest in alternatives to traditional generation resources opened the discussions about DG and the need for interconnection rules. Public utility commissioners from TX and CA were invited to workshops to share their experience and opinions [28].
- WA: Reviews and discussions about DG benefits and need for interconnection rules are currently running as

	Closed Trans-ition	Single-Phase	Three-Phase			
	Capacity					
Feature	≤10 MW	≤50 kW	≤10 kW	10 kW - 500 kW	500 kW - 2 MW	2 MW - 10 MW
PUCT Rule Reference	§25.212-(g)	§25.212(d)	§25.212(e)-(3)(A)	§25.212(e)(3)-(B)	§25.212(e)-(3)(C)	§25.212-(e)(3)(D)
Interrupting devices (capable of interrupting maximum available fault current)	✓	✓	✓	✓	✓	[4]
Interconnection disconnect device (manual, lockable, visible, accessible)	✓	✓	✓	✓	✓	✓
Generator disconnect device	✓	✓	✓	✓	✓	✓
Over-voltage trip	✓	✓	✓	✓	✓	✓
Under-voltage trip	✓	✓	✓	✓	✓	✓
Over/Under frequency trip	✓	✓	✓	✓	✓	✓
Synchronizing check (A: Automatic, M: Manual)	A	A/M [1]	A/M [1]	A/M [1]	A [1]	A [1]
Ground over-voltage or over-current trip	[2]			[2]	[2]	[2]
Reverse power sensing				[3]	[3]	[3]
If exporting, power direction function may be used to block or delay under frequency trip					✓	✓
Automatic voltage regulator						[1]
Telemetry/transfer trip						✓

Notes:
✓ – Required feature (blank = not required)
[1] – Required for facilities with stand-alone capability
[2] – May be required by TDU; selection based on grounding system
[3] – Required, unless generator is less than applicant minimum load, to verify non-export
[4] – Systems exporting shall have either redundant or listed devices

Fig. 4. An example of typical technical requirements for DG interconnections.

part of the discussion on the establishment of a retail market [29].

Along with the individual state initiatives, two major activities are underway:

- The IEEE has drafted a uniform technical standard (IEEE P1547 STD Draft 07), which is expected to be completed during the latter half of 2001.
- Underwriters' laboratories (UL) are developing a UL standard that is harmonised with the IEEE P1547. The UL standard is expected to be ready in 3 years with the first draft scheduled to be ready by the end of 2001. The development is done through a UL project with the US Department of Energy (DoE).

Latest indications are that the large number of broad based initiatives [2,30–33] are focusing generally on understanding the role and contribution that DG installations can have with respect to the present transmission and distribution infrastructure. General principles are developing in concrete proposals for technical and safety requirements (Fig. 4) and installation processing regulations (Fig. 5). However, it is difficult to foresee a common set of technical and installation approval standards being in place across both USA and Europe within the next few years.

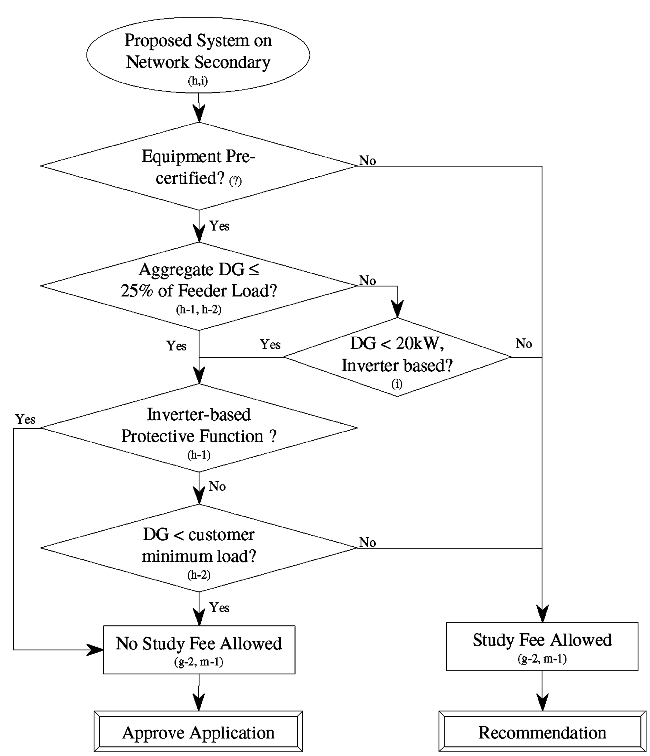

Fig. 5. Possible decision path for installation and connection [34].

4.5. Ownership, costs, charges—non-technical issues

Further to the items referred to earlier which relate primarily to the aspects of safety, reliability and supply quality, there are also a number of issues which stem from financial incentives and the costs involved with installation of DG.

The issues relating to the financial aspects of grid interconnection of DG may require more intensive analysis before agreement can be reached on the best solution for all involved parties. When taken in the historic perspective of energy supply, the consumer is traditionally billed for the energy delivered at the meter. Included in the kWh price is the production cost, the transmission cost and the distribution cost. With the introduction of a DG unit, the user is replacing energy taken from the grid by local supply, and may be injecting energy back into the grid. On the other hand, having paid everything in a kWh charge in the past does not imply that this can be maintained when DG is installed and that the DG user will continue to be charged only for metered kWh. There are a number of issues relevant to the cost of interconnection of DG:

- the value of the energy produced by the DG unit;
- the value of the installed distribution network infrastructure and its servicing (which is no longer being used to supply all of the consumer energy);
- the cost of network adaptation as DG unit installation grows.

With respect to the energy price, net metering[1] is allowed in a number of states in USA and some European countries. It is however still strongly dependent on the local authorities as to the type of installation which can use net metering (e.g. whether cogen is included), and also which type of users (residential, commercial, agricultural, industrial) and what size. Generally, it is used as a means of providing an incentive for renewable energy.

The cost of the network infrastructure and adaptation costs are somewhat more contentious. Maintaining the status quo leads to the situation that those consumers with no DG installed can end up subsidising the DG users, in that they will be charged within the kWh rate for the network costs, including the connections to DG user premises. Furthermore, the utility in a deregulated market that is a distribution network operator, and whose revenues are based on energy flow through the network, will experience loss of revenue for every kWh generated at the DG user site, and this implies that also the utility must look for tariff reforms to maintain the revenue stream. There are many proposals as to how new tariffs may be implemented; however, this may take some time until appropriate schemes are decided.

Although DG is being propagated as an efficient, environmentally friendly power source, and could also be installed by the utility to improve the service in a highly cost-effective manner (reducing costly extensions/upgrades and decreasing system losses) and supply locally produced energy, in the deregulated market structure, it can be difficult or impossible for the local distribution network operator to own and install DG units. The same utility is however required to certify DG installation of 3rd party installers, and also take responsibility for the continued reliability and supply quality of the network. This may be considered as a certain imbalance in the market structure, and may lead to difficulties in concluding cost-effective installations.

5. Conclusion and outlook

The acceptance and integration of DG within the present grid structure and utility environment can be improved by finalising a number of the on-going activities:

- A set of technical standards acceptable to a majority of the participants involved in interconnection issues
  - enabling cost-optimised interconnection (identical requirements across a large number of installations),
  - allowing suppliers to package DG in productised interconnect packages.
- National or International Safety Rules
  - providing simplified approval procedures and understanding from DG owners.
- Review tariff structures
  - ensuring network operators are in a viable position to maintain grid security as DG installations grow.
- Evaluation of DG as a network benefit
  - deciding whether DG should be treated only as generation or be "network equipment"?

Finally, looking into the future, the relationship between DG and network integration will depend somewhat on whether DG will be installed for rather special purposes, for example to overcome utility transmission bottlenecks; for particular commercial and industrial customers (especially those that place high value on uninterruptible power), or whether there will be a paradigm shift in power generation, with large scale deployment, in which DG becomes a major power source [35]. In the latter case, the network will also undergo a long term transformation, in which self-supporting user-groups or co-operatives will be connected by micro-grids.

The micro-grids will be designed for the DG concept and are likely to include a number of new technologies ranging

[1] *Net metering*: Basically, net metering allows electricity flow from and to consumers through a single bi-directional meter rather than insisting on the installation of a two meter system. It is more advantageous for DG users than the two-meter arrangement; since, in the latter case the buy back rate defined by the utility is less than the retail one, and typically set as the utility avoided cost. With net metering, excess generation offsets consumption, and charges are based on the net meter reading. There are a number of compensation methods, simple monthly netting or annual netting with a monthly carry over, allowing for seasonal renewable DG effects. The payment, if any, for surplus depends on the local authority.

from intelligent switches, adaptive protection, and web based information and control systems in which both the local owners and their contract partners have access to the system operation. Within such a ''virtual utility'', the DG units form an aggregated power plant in which the units can be optimised [36], for the good of the co-operative, and where surplus energy can be traded with similar co-operatives over micro-grid transmission interconnections.

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