Distributed Generation Integration Challenges: A Review

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Abstract— Distributed Generation plays a vital role in the distribution system planning as an alternative. The penetration of DERs in distribution network definitely offers potential and benefits. Many researchers and authors have presented rigorous methods for improving the penetration scenario of DGs in the distribution network. This paper reviews the various issues that plays significant role in distributed generation integration. Also, the various methodologies presented yet to solve the major issues and improve penetration scenario have been discussed and the various key findings of the literature review are presented.

Key words: *DER, Distributed generation, reliability, voltage regulation, loss reduction, power quality etc.*

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I. Introduction

The liberation of the energy market and the latest circumstances in the energy field are contributing towards the acquiring of considerably more effective means of energy and management. The introduction of latest strategies competent for evolving in the new conditions may bring on more appropriate possibilities compared to any possible failures the new market model can produce. Energy requirements is anticipated to raise at an annual rate of 1.4 percent concerning now and 2020 [1] as well as , central plants can probably no longer yield competitively inexpensive and dependable electric power to considerably more distant consumers through the main grid, since these plants had come to expense lesser compared to the main grid and as well , had become so reliable that they can cater almost every power outages originated in the grid. Thus, the grid had turn into the main driver of distant client electric power expenses and power quality problems, that are becoming considerably more severe as digital equipment required extremely reliable electricity [2-3]. Efficiency gains no longer come from increasing generating capacity, but from smaller units located closer to sites of demand [4-5]. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the population.

Distributed Generation (DG) or the alternate energy systems is expected to play an increasing role in the future of the power systems. The term Distributed Energy Resources (DER) is used to refer to DG along with storage technologies such as batteries.

The DG is defined as small-scale generation (10MW or less) and can be interconnected at different load levels (substation, distribution feeder or customer).The centralized generation remains the main source of electricity while the DER provides reliability, resilience and transmission & distribution grades to the grid. Large power plants are capital-intensive and require transmission and distribution grids to supply the power.

The technologies for DG are based on reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines. The technologies are also called alternate energy systems as they provide an alternative to the traditional electricity sources i.e. oil, gas, coal, water etc. and can also be used to enhance the current electrical system. DGs are becoming increasingly popular due to their low emission, low noise levels and high efficiency. One of the main advantages of DG is their close proximity to the customer loads they are serving. DG can play an important role in improving the reliability of the current grid, reducing the losses, providing voltage support and improving power quality.

II. Review process adopted

We have followed one of the typical processes to make a literature review of the research carried out in the field of distributed generation. A categorical review of the major issues in the field has been carried out.

Large scale integration of DG units in the distribution system not only affects the network planning but also has a great impact on the operation of the distribution system. The major issues on which the most of the researchers have focused are as follows:

1. Voltage control and grid losses
2. Power quality improvement
3. Protection coordination & fault level detection
4. Reliability assessment

According to researchers the effect of DG units on these issues strongly depends on the type of DG unit and the type of the network. DG units can be either directly connected to the distribution grid, such as synchronous and asynchronous generators, or via a power electronic converter. In all cases, the power flow in the distribution grid as well as the grid losses and the voltage control are affected. Synchronous generators contribute a large short-circuit current influencing the protection scheme and the fault level. DG units connected via power electronic converters hardly contribute to the fault current making the effect on fault level and protection system negligible.

III. LITERATURE REVIEW

In this section the literature of the various issues mentioned in above section has been discussed.

1. Voltage control and grid losses:

DG plays a critical role in distribution system by reducing the flow of energy in the transmission sub-system making the overall system very robust [6].

One of the major advantages of employing DG is improvement of the overall voltage profile of the system. With centralized control, voltage regulation which overlooks the entire power system is possible. Various methodologies of control have been suggested, including SC and LRT (Load Ratio Control Transformer) using a neural network (NN) [7], coordinated control that sends voltage of a substation (tap of LRT) and SVR (Step Voltage Regulator) [8], and a method that decides operating standard voltage for TCR (Thyristor Controlled) and ICR (Inverter Control Regulator) using NN and GA (genetic algorithm) [9]. Others method are on-line control SC of a power distribution systems [10], cooperation control using controllable load in addition to LRT or SVR [11], cooperation voltage control of the transformer tap in consideration of a layered structure [12], determination technique of sending voltage [13], and a method of Heuristic and algorithmic combined approach for reactive power management [14]. In the distribution system with photovoltaic equipment, there is a paper that investigates the FACTS devices inverter minimum capacity aimed at voltage variation within restricted condition [15]. Although, all controllers (LRT, SVR, SC, SVC (Static VAR Compensator)) exist in the real power distribution system, the voltage optimal control of an actual power distribution system is not fully considered. Moreover, the cooperation control in consideration of all the controllers has not been reported.

The optimal placement and sizing of generation units in distribution networks has been continuously studied in order to achieve different aims [16-17], the minimization of total network supply costs, which includes generators operation and losses compensation [18-21], the best utilization of available generation capacity [22], THD reduction [23], and improving voltage profile [24].

A Lagrangian based approach has been proposed to investigate the optimal location of DGs considering economic as well as stability limits in [25]. Various approaches based on Tabu Search, Genetic Algorithm for optimal placement of distributed generators with an objective of minimizing losses, generators operation and losses compensation and the best utilization of the available generation capacity [26-30] have been used. A GA based methodology for optimal DG placement and size in distribution systems, in order to reduce network losses has been proposed in [31]. An analytical expression based on real power loss sensitivity to calculate optimal DG size and optimal location of DG minimizing power losses in a distribution network has proposed in [32]. A hybrid GA-OPF approach has also been proposed for finding optimal location for connecting a predefined numbers of DGs in a distribution network in [33].

Table 3.1 Comparative analysis of solution approaches for loss reduction and voltage profile improvement

S. No	Author & Year of Paper	Technique Used	Remark
1	[F.B. Araujo,et-al,2012, Wang *et al*, 2004; Acharya *et al*, 2006; Gözel *et al*, 2009; Hung *et al*, 2010	Analytical	There is a 5.3% increase in load and a 68.9% increase in losses, ending with a 929.6 kW loss of active power.ch loading value.
2	H. Musa et- al 2013	Combination of Evolutionary Programming (EP) and PSO.	Loses have reduced from 135.7 to 17.17 and voltage is improved from .68 to .81 p.u
3	JIANG Fengli, et-al, 2013	Backward/ forward algorithm	With the increase of capacity of PQ type DG, the power losses reduce gradually.
4	Alireza Dehghani-Arani et al 2013, Haghifam *et al*, 2008: Ochoa *et al*, 2008	Multiobjective optimizing NSGA	Losses have been reduced t0 almost 25%
5	P. Juanuwattanakul et al 2011	Iterative algorithm	DG penetration level of 60% is achieved.
6	Elias K. Bawan,et-al,2012	System modeling(n/a)	Decrease in drop voltage from 14,48% to 6,34% and losses

			from 240,15 kW to 99,39 kW
7	B. Hanumantha Rao et al 2012, Wang *et al*, 2008	Clonal selection algorithm (CSA)	Loss reductions of 44.63%
8	M. T. Arab Yar Mohammadi,et-al,2012, Golshan *et al*, 2006 ; Nara *et al*, 2001	PSO	Active power losses reduces from 465.74kw to 293.36 kw and reactive power losses from 216.44kw to 181.345 kw
9	Israfil Hussain et al 2012	artificial bee colony algorithm (ABC)	67.45% loss reduction, 6.175% voltage profile improvement

2. *Power quality improvement:*

Power quality of grid-connected DG inverters is one of the major aspects that need to be considered while planning DG systems. IEEE 1547 specifies the standards for penetrating distributed resources with electric distribution systems and the conditions that have to be met in terms of voltage, frequency, and other quality measurements.

To mitigate the impact of power quality problem and to improve the power quality in the operation of the PV inverter many efforts have been surveyed. Several methods have been implemented to improve the power quality and control method with better power quality parameters [34–42]. The current distortion caused by reactive power consumption is compensated by designing and adding a reactive power conditioner function integrated in the PV inverter unit. In [34] and [35], this function has been embedded in the current control and MPPT mechanism of the PV-inverters. In [36] and [37], PV-inverter has been designed to enable it to role as a reactive power conditioner unit. In [38], a collaborative of two voltage source inverters are employed for controlling the quality of the current injected into the grid.

Table 3.2 Comparative analysis of solution approaches for power quality improvement

S. No	Author & Year of Paper	Parameters	Remark
1	Milan Prodanovi´, et-al,2006	THD, Voltage	No circulating currents flowing between the inverters
2	Ricardo J. Sousa Lima, et-al,2007	THD of current, power factor improvement	Power Factor improved from .57 to .97 and TDH of current decreased from 72% to 16%
3	Yonghua Cheng,et-al,2006	Voltage fluctuations	Super capacitor based energy storages are very suitable as the peak power units combined with the VSI based Dynamic Voltage restorers to compensate the voltage fluctuation
4	Peerapon Chanhom, et-al,2007	Voltage regulation, reactive power compensation	DSTATCOM with fuel cell can effectively operate as active power source and reactive power compensator
5	Chandana Jayampathi Gajanayake ,et-al,2009	Current and voltage THD	Injected grid current harmonic level is reduced to THD = 4.21%
6	P. Pachanapan,et-al,2009	THD	THD decreases to 4.39 %
7	A. A. Ghadimi, et-al,2010	Voltage regulation	All buses voltages are at standard values (±5%)
8	R. Bojoi,et-al,2010	Current THD	The current source THD value was about 2%.
9	M.Tarafdar et-al 2002(3 different publications)	Reactive power compensation , harmonic compensation	Instantaneous reactive power is compensated in 160 to 200 ms
10	M.Saitou et-al 2002,	Reactive power compensation , harmonic compensation	Instantaneous reactive power is compensated in 200 ms
11	N. matsui et-al 2003, J. Liu et-al 1999, Y. J. Kim et-al 2005, M. Gonzalez et-al 2004	Current THD	THD is reduced to 3.8%
12	Muhammad Imran Hamid et-al 2011	Reactive power compensation , harmonic compensation	THD of 4.83 % and time delay of 400ms

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13	Muralekrishnen.R et-al 2012, N. Hamrouni et-al 2008, Wu Libo et-al 2007, Jose M. et-al 2010	voltage sag, swell	Compensation in 500ms

3. Protection coordination & fault level detection:

Over the last years, much research has been done in fault detection and identification, for which various models, procedures and algorithms have been proposed. Among these Fourier analysis based algorithms and FIR filtering based protection. Recently new techniques had been presented based on wavelet analysis [39]. In [40-42] expert system (ES) technique have been considered. In [40] the author has presented a decision support system DSS that automatically creates rules for knowledge representation and develops an efficient fault diagnosis procedure. In [41] a Bayesian network on the basis of expert knowledge and historical data for fault diagnosis on distribution feeder has been built and in [42] expertise has been shown by logical implications and converted into a Boolean function. Fuzzy approaches have been majorly applied to power system fault diagnosis [43-44]. The fuzzy logic technique offers the possibilities to model inexactness and uncertainties of protection device operations and false data. In [43], a method for the fault section estimation that considers the network topology under the influence of a circuit breaker tripped by the previous fault was proposed. To exercise with the various uncertainties due to the protection systems, the fuzzy set theory has been applied to the network matrix in order to investigate the relationships between the operated protective devices and the fault sections. In [44], a diagnosis system for calculating the fault section of power system by using a hybrid cause-effect network and fuzzy logic has been presented. In recent years, Petri Net (PN) and Fuzzy Petri Net (FPN) technique had gained researcher's interest [45-52]. In [45-48], fault clearance processes were modelled by PN and a reverse PN to calculate fault section. In [46-47] FPN has been used to deal with incomplete and uncertain alarm information of protective relay.

Table 3.3 Comparative analysis for solution approaches for protection coordination

S. No	Author & Year of Paper	Technique Used	Result
1	WANG Ying, et-al, 2011 Peng Mingwei et-al 2009,Zheng Guangminget-al2010, Wang Jiaming et-al 2010	CIM based Relay Protection Model	Analyzes the shortage of protection model in CIM and extends the protection model.
2	QIN LiJun,et-al,2011	Multi-Agent System Wide Area Protection	Intelligent software architecture for the wide-area protection coordination system
3	Manohar Singh, et-al, 2013, S.M. Brahama et-al 2004, A. J. Urdaneta et-al 1988, Chattopadhyay B et-al 1996, Farzad Razavi et-al 2008	Meta-heuristic approach based on covariance matrix adaptation evolution strategy	The optimized value of "OF" is 71.69 (sec.) without DG injection and it reduces to 63.05 (sec.) during DG injection.
4	Jing Ma, et-al, 2011	Adaptive Protection Scheme	the range of the adaptive primary protection is about 80% length of its own line.
5	Pukar Mahat, et-al, 2011, G. Rockefeller et-al 1988, A. Oudalov	adaptive Overcurrent Protection	Stability achieved 120 ms after the fault
6	Lauri KUMPULAINEN,et-al2005	Ripple Control Type of Signal	Feeder trips at t = 1.4 s, and the decrease of the signal level rapidly indicates the islanding.
7	H. H. Zeineldin,et-al, 2013	protection coordination index (PCI)	The results were obtained for 0.3 sec and a maximum relay operating time of 2.5s.
8	Manohar Singh,et-al,2013	Hybrid Protection scheme	CTI improves from -0.417 second to -0.13 second. Further improvement from -0.13second to 0.3 second is achieved through FCL.
9	S. A. A. Shahriari, et-al, 2010	Solid State Fault Current Limiter	Fault current level reduced from 2KA to .5 KA

Up to now, very few methods have been reported for identification of the fault location in power system with a high penetration of DGs.

4. Reliability Assessment:

Increased reliability and reduced cost are the primary incentives of adding DER to a power network. DG is mostly used as standby or backup power in utility supply interruption.

In [53], the positive impacts of DGs to the distribution network such as reactive power compensation to achieve voltage control, reduction of losses, spinning reserve to support generation outages and improvement in reliability through backup generation were reported. In [54], an optimal placement and sizing method of DG in a distribution system has been presented and used to improve system reliability. In [55], a methodology to investigate loss has been discussed. In the proposed approach, the author correlates the hourly load to the output of the unconventional units and assigns them to specific states using a clustering algorithm. In [56], a time sequential simulation to estimate the reliability of a distribution system with wind turbine generators (WTG) has been presented. The power output of the WTG at a specific hour was expressed as a function of the wind speed at that hour, and the rated power of the unit. The authors in [57] presented a Monte Carlo method for the adequacy assessment of a distribution system with DER. The total output power of the working DGs was treated as a random process attributed to the random nature of the DG duty cycle, its failure rates and restoration times. In [58], author used an hourly reliability worth assessment of a distribution system to determine the optimal operating scheme for DGs. According to the authors [58], in order to determine the optimal strategy for the DG operation, the reliability worth should be balanced with the cost of power through a suitable combination of the two operating modes.

Table 3.4 Comparative analysis of solution approaches for reliability issue in DG Penetration.

S. No	Author & Year of Paper	Technique Used	Remark
1	George Papaefthymiou, et-al, 2005	Monte Carlo Simulation (MCS)	presence of stochastic generation in the system results to highly bidirectional power flows.
2	A.M. Abdullah,et-al,2012	Analysis	The total profit varies from +9% to -40% of profit increment compared with the regular profit.
3	Wang et al, 2008, (Chu et al, 2004; G´omez et al, 2004; Teng et al, 2003	Ant colony system algorithm	Optimize the re-closer (or DG) placement for a fixed DG (or re-closer) allocation to enhance the reliability

IV. KEY FINDINGS

After studying and analyzing the literature of the research carried out for different issues in integration of distributed generation, some of the key findings have been mentioned.

1. The different techniques such as particle swarm optimization, optimal power flow method, fuzzy optimization method, loss sensitivity analysis, Discrete particle swarm optimization (DPSO), Genetic Algorithm, Bellman-Zadeh algorithm, Tabu search, ant colony system etc have offered promising results and also have been used effectively for voltage profile improvement and loss reduction in distribution system.
2. The results of all simulations studied indicate that different location and capacity of DG can significantly affect the system voltages and losses.
3. The combination of Evolutionary Programming (EP) and PSO has reduced the losses up to 80% and voltages are also improved. This technique has given best results as compared to other techniques.
4. The Multi objective optimizing has been used for voltage unbalance factor and increased economic profit.
5. Distribution systems are not designed to accommodate DGs as they might cause bidirectional power flow and other potential problems and unexpected conditions. The large reversal of power flow in the system may result in over voltages at some distributed PV locations and increased losses due to high currents in the conductor.
6. Different software such as GARP3, E-Tap, Simulink, MATLAB, PSCAD, Direct Search Toolbox TM etc has been used for simulation for the different proposed methodologies and algorithms. It is necessary to recognize that the use of appropriate parameters to find the optimal DG location is essential for the current distribution system planning.

The authors are interested in Power Quality improvement mainly due to economic reasons. The main challenge for power quality improvement is to coordinate the actions of a group of inverters so that they offer the level of power quality known to be possible from fast local control of a single inverter. In small girds, it is also important to actively control the waveform quality in terms of harmonics, transient disturbances, and voltage balance. The efficiency of the system increases with the level of the input current and consequently the generated power quality. The detection methods of some traditional power quality disturbances of power system connected with DG such as voltage deviations, frequency deviations and three-phase unbalance are quite mature. The unused or remaining capacity of the converters could be used to provide some ancillary functions like harmonic and unbalance mitigation of the power distribution system. A simple solution to the increased current harmonics is by cancelling harmonics generated by the non-linear load (connected downstream of the PCC) from the DG system.

Protection is a crucial feature of conventional electricity grids, and relies on the well understood principle of detecting elevated currents in the event of a fault. The future grid is likely to incorporate a significant amount of renewable and other distributed generation, which may affect operation of protection systems. One of the most considerable problems that arise, when DG is used, is destructing efficiency and qualification of the existing protection system. The injected currents of DG to a distribution network lead to not having a radial network anymore, and consequently causes the network faces an inefficient protection system that was formerly designed according to the existing philosophy behind the distribution network. Increasing penetration of distributed generation resources causes protection coordination failure in distribution system. Each incoming DG in distribution system causes the reconfiguration of distribution network. Coordination of over current relays is effected which were earlier set for radial configuration of distribution network. We need more relays with directional features. Moreover, the setting of over current relays is updated with the help of adaptive protection scheme, which optimizes the relay setting. Anti-islanding protection is an important technical requirement when interconnecting distributed generators. Voltage relays are not suitable to detect the islanding of a synchronous DG if the excitation system is configured to the control terminal voltage. The trip characteristics of the relays are updated by detecting operating states (grid connected or island) and the faulted section. Ripple Control Type of Signal technique trips the feeder in t = 1.4 s, and the decrease the signal level rapidly indicates the islanding.

The reliability worth analysis provides an indirect measure for cost implication associated with power failure. The system losses reduce by 80% with DG placement and further reduce to 85% with network reconfiguration. The stochastic nature of the renewable resources and their influence on the reliability of the system are modeled and studied by computing the adequacy transition rate. The type and location of switches are expected to play a key role on the reliability improvement of power distribution systems. The penetration of DGs can improve interruption duration and does not effect on the interruption frequency of the system. Reliability worth analysis method is a proper way to make decision for planning the system and is under study and will be reported in future work. The reliability worth analysis provides an indirect measure for cost implication associated with power failure. The power generation, transmission & distribution system must be able to supply uninterrupted power reliably while maintaining the power quality throughout. The constraints like the generation capacity and system disturbances, affect the reliability and overall performance of system adversely.

V. Conclusion

A categorical review in the field of distributed generation sources integration in distribution network has been carried out. Different issues for integration of DGs have been classified. Various methodologies for voltage profile improvement, power loss reduction, power quality improvement and reliability assessment have been discussed and listed. Also, the key findings from the review had been presented.

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