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Investigation and Implementation of Power Quality Improvement Strategies Using Custom Power Devices for Enhanced Electrical System Functionality

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Abstract— Distributed power generation is the latest field because of the ability to accommodate various types of Renewable/alternativeenergy sources, its hidden potential to improve the energy efficiency andpower system capability, and its promise for power reliabilityand security. Many distributed energy sources exists such solarenergy, fuel cell, micro turbine, and wind energy. Distributedpower generation concept has been implemented in various placeswith various degree of complexity. A comprehensive review onthe distributed power generation is presented in this paper.

Index Terms—*Distributed generation, renewable energy sources*

I. INTRODUCTION

Distributed Generation (DG), when fully implemented, canprovide reliable, high-quality, and low-cost electric power. Asa modular electric power generation close to the end user, itoffers savings in the cost of grid expansion and line losses. Ifconnected to the power grid, the bi-directional transactionsbetween the grid and the local generation result in gridcapacity enhancement, virtually uninterrupted power supply,and optimum energy cost due to the availability of use/buy/sell options.

Distributed power is a concept that covers a wide spectrum of schemes used for local electric power generation fromrenewable and non-renewable sources of energy in an environmentally responsible way. Main schemes are mainly basedon solar energy, wind energy, fuel cells, and micro turbine engines.

Twenty years ago, almost all the electric power was generated at large central power stations; twenty years from now, agood part of this power it is expected to be generated by small power units that will be distributed throughout the service grid.Since such units are located close to the customer, they areexpected to better meet the customer’s needs.In parallel to the introduction of distributed generation, the legislative framework for the electricity sector is under going major changes in many industrial countries. These changes aredriven by a moving towards more liberalization in order to create a competitive market environment. Within this competitive environment, decentralized power generation has to compete with centralized power generation. It is, however, often argued that electricity market regulations for competitive electricity markets do not provide an equal treatment of centralized and distributed generation. In order to become more familiar with the concept of DG,its definitions in some different countries are given here forcomparison.Swedish legislation gives special treatment to small generation capacity of up to 1500 kW. Under Swedish law, awind farm with one hundred 1500 kW wind turbines is still considered DG, as the rating of each wind energy unit, andnot the total wind farm rating, is relevant for the law. But forhydro units, in comparison, it is the total rating of the power station that is relevant. In the English and Welsh power market, DG plants with acapacity of less than 100 MW are not centrally dispatched and if the capacity is less than 50 MW, the power output does nothave to be traded via the wholesale market.In New Zealand, DG is often considered generation of upto 5 MW. According to new electricity market regulations, distribution network owners/operators use 5 MW as a guideline for determining whether approval should be sought bythe distribution network owner/operator from the national grid operator for the generation to be connected to a distributionnetwork.There is no special definition for DG in many countries, such as California and Norway.Different definitions of DG are, however, not only used within different electricity market regulations, but also in therelevant literature. To avoid confusion by different definitions,a general definition for distributed generation is suggested:“Distributed generation is an electric power source connected directly to the distribution network or on the customer side of the meter” [1].In the following sections, different sources of the distributedgeneration will be introduced and the application of each of them will be discussed.

II. FUEL CELL

Fuel Cells (FC) are electrochemical devices converting thechemical energy content of a fuel directly to electrical energy.Fuel cells should be supplied with the fuel to the anode andoxidant (e.g., air) to the cathode. They perform a conversionequivalent to the different stages of traditional extractionof energy in the form of combustion heat, conversion ofheat energy to mechanical energy (as with a turbine), and finally turning the mechanical energy into electricity (as witha dynamo or a synchronous generator) in one shot. Theycombine the molecules of a fuel and oxidizer without burning, dispensing with some of the inefficiencies and pollution oftraditional combustion.Their output is a dc voltage that can be converted to anac voltage by using an inverter and used locally or fed to the network. A Fuel cell is potentially the most efficient and modern approach to electric power generation. The efficiencyof the conversion, i.e., the ratio of the electrical output tothe heat content of the fuel, could be as high as 65-70%.In fact, its electrical efficiency could be greater than 70% in theory. The current technology has only been capable ofreaching efficiencies of around 45%. Combined cycles areenvisaged to bring the electrical efficiency of plants based on high temperature cells up to around 60% [2]. The differenttypes are: polymer electrolyte membrane, phosphoric acid,molten carbonate, solid oxide, alkaline, direct methanol fuelcell and regenerative fuel cell [3].

III. SOLAR ENERGY

Photovoltaic (PV) cells are devices that convert sunlight toelectricity, bypassing thermodynamic cycles and mechanicalgenerators: sunlight photons free electrons from common silicon generating e.f.m vat the PV terminals. The phenomenonwas first discovered in the 18th century and the early photovoltaic cells were developed at Bell Labs in 1950, primarily for space applications. Solar cells have proved to be cost effective. Other than spacesatellites, the photovoltaic cells are being used in rural health clinics for refrigeration, water pumps for irrigation and forsmall-scale power generation. Since the output power of the solar cell depends upon theinsolation level, and also at a specific insolation level, theI-V characteristic of a solar cell is a nonlinear relationship,different methods have been developed to locate the maximum power point of the cell, i.e., the operating point at whichmaximum power can be obtained from the cells [4]. Onedrawback of photovoltaic generation systems is the large areathat is required to produce a considerable amount of electricalenergy. The other drawback is that on some days, the insolationlevel is not high enough to produce the expected energy. This lowers the reliability of the system [5]-[6]. Photovoltaic generation systems need to be connected to thegrid that acts as a pool of energy that can be taken from oradded to, depending on the insolation level and the level oflocal consumption. In stand-alone mode of operation, sometype of energy storage, such as a battery or a supercapacitor, This has to be used to store the extra energy in or to get thenecessary energy from, when the local generation is notenough.Conventionally, a two-stage PV energy conversion system isemployed to connect a PV array to an electrical power system.The first stage, i.e., the DC/DC converter is controlled so as totrack the maximum power point of PV arrays, adjust the levelof the voltage for the next stage, and transfer energy to thebatteries and the inverter. The second stage, i.e., the inverter orDC/AC converter, is controlled to produce an output voltageof grid quality, in stand-alone mode, or an output current inphase with the utility grid voltage to transfer power to thegrid at unity power factor, in grid-connected mode. As the DC/DC and DC/AC converters have independent architecturesand control goals, the controllers are easy to design. Yet, theefficiency of the entire conversion system is compromised because of the large number of individual devices, i.e. theDC/DC converter, batteries and the DC/AC converter [6].

IV. WIND ENERGY

wind energy is another DG source, which can be convertedto electrical energy. The speed of the wind can be quitevariable. Besides, some areas are not windy enough to extractconsiderable amount of energy from the wind. The renewable energy sources such as wind, solar, etc.,play a major role as electrical and mechanical energy supplies, not by replacing the conventional energy sources butsupplementing them. The world is faced with a range of environmental issues that threaten ecosystems, health, economy and way of life. With increased public awareness of the roleof the electricity sector in these matters, and the likely future customer choice in electricity and energy supply, industry willcome under increasing expectations to reduce gas emissions.Preferred solutions to prevent emissions include energy andresources conservation as well as renewable and cleaner energy sources. The issue of global climate change is a result of fossil fuelcombustion. In such an altered environment for the selection of new power plants, public attitudes will become much moreimportant than they have been in the past. The public wouldlike to protect the environment and, in particular, takes care of the environmental problems related to human life, such as airpollution. Also, the population strongly prefers using a combination of efficiency and renewable to meet energy needs [7]. Public polling information from United Kingdom shows thatwind energy primary positive points are its environmentally friendly, renewable, and safe nature, as well as the fact that ithelps to conserve fossil fuels. Surveys show that WG principalweaknesses are in that wind is intermittent and such a kindof electric power is more expensive than fossil-fired power.

Somebody awares for their acoustic noise. The public supportfor wind has strengthened after wind plants were installedand operated for some time. In Alberta, Canada, a small 10MW wind power plant prevents the emission of nearly 23 billion kg/year of sulphur oxides, nitrogen oxides, and carbondioxide, that would otherwise be produced by conventional power plants [7].Due to the variations in the wind speed, most of the windenergy schemes are based on induction generators, as there is no stiff link between the rotational speed and the outputfrequency in this kind of machine. Besides, the reactive powersource at the induction machines terminals plays a role to determine the output frequency [8].Wind energy-based DG can be operated in either grid connected or stand-alone mode. Reference [8] proposes thescheme shown in Fig. 1, using a wind turbine as a grid connected power source. The real power can be changed byadapting the blade pitch angle, whereas the reactive power is changed by the reactive power source at the terminals ofthe induction machine. In this figure, IG and SVC stand forinduction generator and Static Var Compensator, respectively.

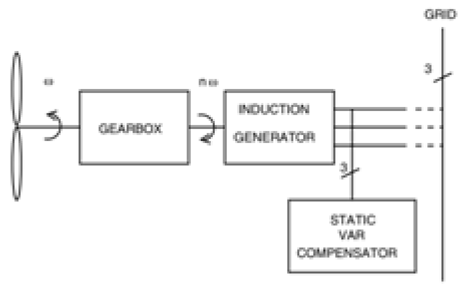

Fig. 1. Wind turbine-based distributed generation scheme

Researchers have come up withdifferent methods to track this maximum point to utilize thewind energy most efficiently. A major problem with windmilltechnology is in finding the control technique that enablestracking of the maximum point and extracting the largest possible amount of energy from the wind [9]-[11]. Anotherproblem is that the turbine cannot rotate beyond a specificspeed.Due to the above advantages of wind energy, todays windindustry at 2.5 billion dollars a year, represents a globalbusiness for which countries should prepare good strategiestowards integrating wind power in increasingly competitiveelectricity markets. Unfortunately, just in a few countries, thereis a solid market for wind industry and most countries do nothave a political or economic base for this kind of industry. To date, over 80% of the global wind capacity is installedin Germany, USA, Denmark, and Spain, where the electricityfeed laws have been introduced to stimulate a market forrenewable energy sources. These laws are characterized by their system of premium prices which have proved supportiveof wind power. However, it is not easy to integrate windenergy into electricity markets which are traditionally basedon large suppliers of thermal plants. Wind power meets somebarriers when it is compared economically with traditionalpower sources. In this respect, it is important to mention the following points:

- Wind has the disadvantage of being intermittent whichraises questions about grid access and costs
- In best cases, wind plants have ranged from 1MW to30 MW in size, while combined-cycle gas turbine

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power plants (the current industry favorite) have a capacitybetween 50 and 500 MW. The current generation of wind turbines only has a few yearsor less of operation. This leads to the question on reliabilityand, indirectly, makes investment risky.

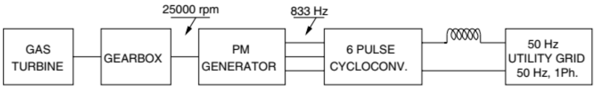

Fig. 2. The scheme proposed by [12]

V. MICROTURBINE-BASED ENERGY

There are some distributed power schemes based on themicro turbines as the prime mover for the generator. In theseschemes the generator connected to the micro turbine is asynchronous machine whose output voltage has a frequency directly proportional to the angular speed of the micro turbinesshaft. It has been proven that using a micro turbine- basedpower generation in parallel with the utility grid can effectively improve the reliability and minimize peak loads, and also mayeliminate the need for reserve margin (standby) and may ormay not sell back excess generation [12].The prime mover of the generators in the above schemes canalso be a diesel engine. Reference [11] suggests a combinationof diesel engine and permanent magnet generator. This schemehas been designed to work in stand-alone mode. Since the diesel engine is not operating at a very high speed, the outputfrequency does not need to be changed and the output voltagecan be directly applied to the load. In order to keep thevoltage of the generator terminals constant a reactive powercompensator has been placed across the terminals of themachine.One of the schemes that has been used before, includesa turbine or high-speed engine, as the prime mover, and a gearbox to reduce the output speed and regulate it so thatthe output frequency of the synchronous machine is equal tothe grid frequency. In this scheme the gearbox is a mechanicalcomponent and mechanical systems show longer time responsecompared to electrical systems. Besides, the system will be lossy, heavy, and bulky. Reference [12] suggests a system using a cycloconverter toconvert the frequency. The block diagram is shown in Fig. 2.A 6-pulse non-circulating current cycloconverter (833 Hz to50 Hz) is used as the frequency changer for a high frequency permanent magnet generator. This generator-converter unit isdriven by a high-efficiency, high-speed gas turbine in thepower range of 250 kW to 870 kW. This system is intendedfor use in total energy systems or hybrid systems in vehicles and high-speed vessels.

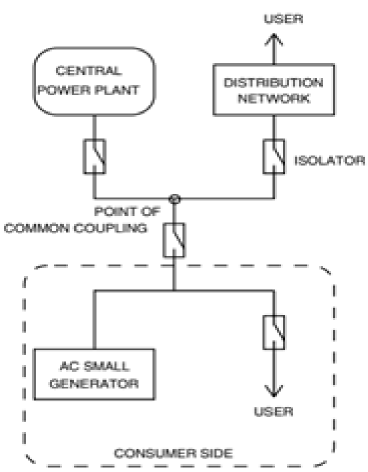

Fig. 3. Demand side DG configurations with utility services

If a high-speed gas turbine (75000 rpm) is used, low-volume and high efficiency power generation results. However, a high ratio gearbox is required to adjust the turbine speed to the generator speed which is dictated by the grid frequency. This scheme cannot attain a high efficiency due to the presence of gearbox and unavoidable mechanical losses.

VI. DGS OPPORTUNITIES AND CHALLENGES

A. Opportunities

Given the potential and probable application of interconnecting the dispersed DG “stand-by generating systems”,generating capabilities provide several benefits to both utilityand consumers.The consumer will have consumption choices; they canreduce their energy expenditures by incorporating DGs that are powered by cheaper fuel sources, for example, the use ofmethane gas fueled turbine-generating units. Methane gas canbe produced in a nearby landfill. Heat can also be produced through the burning of waste in incinerators; otherwise itwill be produced using electricity. Using local or near by fuel sources that could be generated from large amounts ofmunicipal waste that otherwise need vast landfill sites adds tocities’ energy supply chain.As for the utility, it can use the DG power to enforce itsdistribution network voltage stability, as well as to increase itspeaking capacity without suffering financial costs.Fig. 3 shows a typical demand-side DG system that isconfigured to supply both the consuming side as well as feeding the utility during the peak demand period or as acoordinated power quality system enhancement. By allowingconsumers’ own DG units to provide electricity during high electricity rate and short-term supply interruptions, continuousproductivity is ensured and the reliability and power quality ofthe consumed electricity is increased. DG owners or operatorscould also receive a new source of revenue from electricitysales to the hosting electricity provider.Employing renewable energy sources on a large scale willhave a positive impact. For instance, solar power stationsare non-polluting and can provide electricity economically insuitable locations. In many large cities, photovoltaic units are incorporated into new buildings, either on the roof or in thecladding, and supply up to 30 percent of the household demand for electricity.

B. Challenges

For successful integration of DG with Utilities, clear interconnection requirements must be formulated. A broad range of industry representatives have been participating in the development of a new standard for DG/Utility interconnection. An example of these activity is the undergoing IEEE standardP1547, which is meant to provide a uniform standard for interconnection of distributed resources with electric powersystems. Since the introduction of DG provides an unwantedsource for re-distribution of both load and fault current, as well as possible source of over voltage and islanded operation[13], the investigated requirements are looking at issues such as performance, operation, testing, safety and maintenanceof the interconnection. The current engineering practice forDG/Utility interconnected systems is to revert the utility systems to its original configuration (radial or meshed distribution system) with all interconnected DG units de-energized whenever an unexpected disturbance occurs in the system.Since most distribution systems comprise radial feeders, thispractice leads to the discontinuation of the supply for all thedownstream customers. Thus, the system reliability stays at thesame level as it was before integrating the DG with the system[14]-[16]. At the same time, there exist in the system some unsupplied loads and unutilized DG capacity. If interconnectedDGs are permitted to supply loads during utility

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outages, thesystem reliability will be much better and the customers willnot experience any discontinuity of their supply. This goal canbe achieved by simply coordinating intention islanding of DG units [17].

VII. DISTRIBUTED GENERATION ATTRIBUTES

For successful matching of the renewable energy sourcesas the prime fuel and distributed generation, it is worthwhilelooking at the sources attributes and measure how the system will be apply to meet the continuous rise in electricitydemand. DG fuelled by RES is emerging technologies usingcontinuously replenished energy sources. Various sized of DG systems are increasingly being adopted and integrated invarious countries to meet the increasing demand for heat andelectricity. Electricity from RES has proved to be viable, andcan meet up to 20 percent of electricity needs, in the caseof wind energy in Germany and Denmark [18]. A schematicdiagram illustrating the main components of a grid tie windenergy generation system is shown in Fig. 4. Here, the windpower is converted into mechanical power that drives thegenerator. For utility integration, the generator system requires an electronic regulator to control the electrical voltage output,as it varies with the wind intensity, to the level and standardsfor integration with the existing utility network voltage.Energy attributes address theinvestment as well as thesustainability issues for providing electricity. It is difficultto merge RES without defining their attributes against wellknown sources such as coal. The National Renewable EnergyLaboratory, NREL, defines the attributes listed below. NREL isthe principal research laboratory for the Department of Energy(DOE) Office of Energy Efficiency and Renewable Energyin the USA. Some of the listed attributes are quantitative

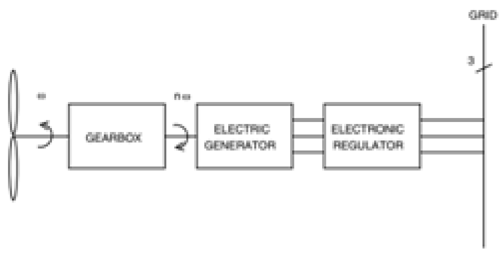

Fig. 4. Main stages of integrating wind energy renewable source for powergenerationin nature, such as capability, capacity and cost, while otherscan only be considered in a qualitative way, such as indirectbenefits and risk diversity. The attributes are:

- Capability: A measure of the capability of the power plantto deliver its designed full load capacity in a given period under normal conditions.
- Availability: A measure of how long power will beavailable. Routine maintenance, unplanned maintenance (i.e., breakdowns), refuelling, and modifications are prime causes of unavailability in conventional power sources.
- Dispatchability: A measure of the degree of control thatthe power plant/utility could exercise over the hour-byhour and minute-by-minute system output.
- Modularity: Modularity has implications for installation, increased capacity, availability, and capital investment risk. Using modular generating units allows expansion, when it is required, by adding more units of the samedesign and size.
- Location: Some power plants are built very close tothe energy source, which is not necessarily the optimum allocation for consumers.
- Cost: Refers to the cost of capital investment, operationand management, and costs incurred or avoided as theresult of employing a technology.
- Incentives: The subsidies provided by the government topromote the development of a technology.
- External costs and indirect benefits:

The costs and benefits, theoretically borne by others, of operating a technology for which the others receive no compensation or make no payment. For example, there are manyproperty owners who have installed solar thermal andphotovoltaic (PV) systems on their property. The installed PV system is in many cases supplying almost 30% ofthe required energy to that household, which otherwise would be provided by centralized power plants through the grid. The benefits are shared, but not the costs, whichare borne directly by the owner and indirectly by theprovider. The provider is relieved from his commitmentto increasing capacity and the related financial burden. These external factors may also include environmental and regional economic impacts.

Risk diversity: Risk describes any unanticipated, unfavourable condition, including unpredicted availabilityproblems with a technology, adverse changes in market conditions, and unexpected changes in legislation.

CONCLUSION

In this paper, a short introduction about all different sourcesof distributed generation was given. Fuel Cell, Solar Energy,Wind Energy, Micro turbine were named as the main sources for distributed generation. Each one was discussed and brieflycompared to each other. It is worth noting that most sourcesavailable for DG are renewable. The use of different technologydepends on several factors including plant location and systemspecification; somewhere a combination of them is a good choice. It is expected that in the future a good part ofthe electrical energy will come from DG. A more detailed discussion about these different sources will be given in thefollowing papers.

References

[1] T. Ackermann, G. Andersson, L. Soder, “Electricity Market Regulationsand their Impact on Distributed Generation”, Peoc. of Int. Conf. onElectric Utility Deregulation and Power Technologies, 2000, pp. 608-613.

[2] J. Padulles, G. W. Ault, J. R. McDonald, “An Approach to the DynamicModelling of Fuel Cell Characteristics For Distributed Generation Operation”, IEEE Power Engineering Society Winter Meeting 2000, Vol. 1, 2000, pp. 134-138.

[3] http://216.51.18.233/fctypes.htm, Fuel Cells 2000, March 2002.

[4] T. Kim, Ho-GyunAhn, S. Park, “A Novel Maximum Power Point Tracking Control For Photovoltaic Power System Under Rapidly ChangingSolar Radiation”, Proc. of IEEE-ISIE 2001, 2001.

[5] R. Billinton, “Capacity Expansion of Small Isolated Power SystemsUsing PV and Wind Energy”, *IEEE Trans. on Power systems*, Vol. 16,No. 4, November 2001, pp. 892-897.

[6] T. J. Liang, Y. C. Kuo and J. F. Chen, “Single Stage Photovoltaic EnergyConversion System, Electrical

Power Applications", *IEE Proceedings*,Vol.: 148, Issue 4, July 2001.

[7] L. Surugiu, I. Paraschivoiu, "Environmental, Social and EconomicAspects of Wind Energy", Energy Conversion Engineering Conference and Exhibit, 2000 (IECE), 2000, pp. 1167-1174.

[8] E. S. Abdin, W. Xu, "Control Design and Dynamic PerformanceAnalysis of a Wind Turbine-Induction Generator Unit", *IEEE Trans. on Energy Conversion*, Vol.15, No. 1, March 2000, pp.91-96.

[9] M. Komatsu, H. Miyamoto, H. Ohmori and A. Sano, "Output Maximization Control of Wind Turbine Based on Extremum Control Strategy",Proceedings of the American Control Conference, 2001, pp. 1739-1740.

[10] M. W. Davis, A. H. Gifford, T. J. Krupa, "Micro turbines- An Economicand Reliability Evaluation for Commercial, Residential, and RemoteLoad Applications", Vol. 14, No. 4, November 1999.

[11] M. A. Rahman, A. M. Oshieba, T. S. Radwan, E. S. Abdin, "Modellingand Controller Design of An Isolated Diesel Engine Permanent MagnetSynchronous Generator", *IEEE Trans. on Energy Conversion*, Vol. 11,No. 2, June 1996, pp. .

[12] N.H.M. Hofmeester, P.P.J. van den Bosch, "High frequency Cycloconverter Control",PESC'94 Record, 1994, pp. 1071-1076.

[13] K. A. Nigim, and Y. Hegazy, "Intention Islanding of Distributed Generation for Reliability Enhancement", IEEE- PES Annual Meeting, 2003,p. 2451.

[14] P. Barker, "Determining the Impact of Distributed Generation on PowerSystems: part 1- Radial Distribution Systems", IEEE, 2000, pp.16451656.

[15] R. C. Dugan, and S. K. Price, "Issues for Distributed Generation in theUS", IEEE Power Engineering Society Winter Meeting, vol.1, 2002, pp.121- 126.

[16] L.A. Kojovic and R. Willoughby, "Integration of Distributed Generationin a Typical USA Distribution System", IEE- CIRED 2001 Conf. Rec.,conference publication No. 482, 2001, pp. 18-21.

[17] N. R. Friedman, "Distributed Energy Resources Interconnection Systems: Technology Review and Research Needs", National RenewableEnergy Laboratory, report SR-560-32459, 2002.

[18] Global Wind Energy Council (GWEC), "Global Wind Power ContinuesExpansion", Press Release, Brussels, March 2005.