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Distributed Energy Resources Electrical Systems: Future prospective

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ABSTRACT. *Distributed generation (DG) is an approach that utilizes small scale technologies to generate electricity close to the consumer side. Generally, DG can provide high reliability, high security, low-cost electricity, and less environment impact. This paper gives an overview of some of the most significant issues related to the distributed generation (DG). It discusses different aspects of DG, such as definitions, technologies, motivation for moving to DG, some drawbacks associated with the centralized systems which have led to DG. DGs challenges, standards and polices are also presented. In addition, the economic impact, and a price comparison between central power plants and DGs are discussed. Also, a case study was conducted in order to study the impact of using distributed generations in Edmonton downtown. Three distributed generations, combustion turbine types with 25 MW capacities each have been implemented in Edmonton power system. The total cost estimations have been studied in this case, and the results have revealed that this type of distributed generation is inexpensive and more economic compared with price from the utility. It was estimated from the calculation that the price for the energy is about ¢6.27/kWh while the current electricity price from the utility is ¢8.561/kWh, for long term estimation it is found that the proposed CTs in this project has 11 years for a payback period, after that the project start earning money which is relatively good and wroth investment. The second part of the study analyses the impact of DGs on the system losses using Power-World software, and the result have proven that the loss is significantly decreases when the DG systems are in operation, hence DGs help reducing the costs that associated with the system's losses.*

Keywords: Distributed generation, Centralized generation, Environmental Concerns, Economic Impact.

1. Introduction.

Distributed generation (DG) generally refers to small scale electric power generators (typically 1 kW – 50 MW) that produce electricity at a site close to customers or that are interconnected at the substation, distribution feeder or customer load levels [1]. It is expected that DG will play an important role in the electric power system in the near future. Distributed generation is not a new concept. The earliest power utilities were using DG to generate and transmit electricity. Then the centralized power systems have been introduced to make large interconnected systems to ensure more reliable and more economic power systems.

Recently, DG has gained a lot of interest in the power industry, the reasons behind this recent restoration for this concept is due to market deregulation, as in the current deregulation, it is hard to stimulate market players and stakeholders to invest multi-billion dollar in power generation and transmission projects where the payback time may be very long. Additionally, the liberalization of the electricity markets, along with the massive increase in demand for electricity, the environmental concerns, the development of new DG technologies, and the limitations in the ability to site new transmission lines, all these factors and others have made DG an attractive option for utilities and industries [2] .

DG technologies include renewable sources of energy, such as photovoltaic and wind. Conventional sources, such as fossil fuel fired reciprocating engines or gas turbines could be used in DG for reliability and power quality consecration. Recent developments in DG technologies have created a substantial role for DG in the future energy due to its improved performance, reliability, and flexibility to achieve higher energy efficiency, fewer environmental problems and reduce emission.

This paper will provide an overview of the DG technology including economic, environmental, technological impacts of this technology. Also, policies, challenges, recent development, and future of DG will be addressed. Moreover, a comparison between the central power system and DG concerning of the cost of the electricity, the capital cost, operation cost and the power transmission cost will be discussed in this report.

Additionally, Edmonton downtown power system has been studied as a study case. Three combustion turbines with 25 MW capacities each were implemented in Edmonton power system. Estimations of the total cost including: the capital, maintenance and fuel costs were studied, and the results have shown that this type of distributed generation is more economic. Then the impact of distributed generations on the system losses have been analyzed, and the results have showed that the loss is drastically declined during the operation of DGs, in such a case the costs that related to the system' losses is decreased.

2. DG Definition

Many definitions are used in the literature to define the distributed generation (DG). For instance, the term 'embedded generation' is used in Anglo-American countries, the term 'dispersed generation' is used in North America, and in Europe and parts of Asia, the term 'decentralized generation' is applied as a DG [3]. The definition of DG varies between countries. Some countries define DG based on the capacity of the units; others based on the location of the system. There is no universal definition for the capacity of DGs. The following are the most common use definition in the literature:

- IEEE defines the DG as a facility with power capacity that less than the centralized grid, usually less than 10 MW [4]
- The US Department of Energy (DOE) defines DG as follows [5]: "Distributed power is modular electric generation or storage located near the point of use. Distributed systems include biomass-based generators, combustion turbines, thermal solar power and photovoltaic systems, fuel cells, wind turbines, micro turbines, engines/generator sets, and storage and control technologies. Distributed resources can either be grid connected or independent of the grid. Those connected to the grid are typically interfaced at the distribution system". The DOE considers a system DG with capacity range from less than kW to tens of MW [5].
- The Electric Power Research Institute (EPRI) considers DG as storage devices that are located close to the customer side with capacity from a few kW up to 50 MW [6].
- According to the Gas Research Institute, the system's capacity between 25 kW to 25 MW is considered as DG [7][3].
- Swedish legislation defines that DG capacity in Sweden is defined under 1500 kW [3] [8].
- The International Council on Large Electricity Systems (CIGRE) considers DG capacity is smaller than 100 MW and is not centrally planned, and not centrally dispatched [9].
- In the English and Welsh power markets, DG is referred to any generating unit under 100 MW in this market [8].
- In New Zealand, usually DG units are having capacity less than 5 MW [3].
- In Australia, generating units less than 30 MW are considered as DG [8]

3. DG Growth worldwide

In 2003, the installed capacity of DG in the US was about 168 GW, at most containing reciprocating engines for backup power [10]. In Canada, in 2000, there were about 7.7 GW industrial cogeneration capacities and less than 500 MW of renewable energy technology capacities including PV, wind power and tidal [11]. In Europe, the installed capacity of DG is evaluated to be about 50 GW, including wind turbines and small hydro systems [12].

In Europe, distributed generations are growing in demand, as they are seen to meet the energy challenges of the 21st century. For example, In Denmark, roughly 57% of electrical capacity produces from combined heat and power (CHP) and 31% from renewable sources of energy this has an important role to enhance CHP and renewable energy technologies [2].

The capacity of electricity generation in the world was around 3365 GW in 2001, utilizing thermal units, hydro plants and nuclear plants, these units roughly accounted for 67%, 21.2%, and 10.7% respectively. About 1.1% was generated from other sources of generation [10]. This capacity is predicted to increase to be about 4000 GW by 2010 and 5000 GW by 2020 [2].

In 2001, the US had 813 GW of electricity generation capacity which was estimated to grow to about 1070 GW in 2010, while Canada, in the same year (2001) possessed 111 GW and this capacity was expected to increase up to 130 GW by 2010 [2][14][15]. Additionally, by 2020, it is expected that 3000 GW new generation capacity would be required worldwide to meet the demand for electricity. It is also predicted that DG would contribute by about 1500 GW [20].

According to the Distributed Power Coalition of America (DPCA), over the next two decades DG would participate in about 20% of all the new generating capacity in the US [16]. It was projected that in 2010, DG market would be in the range of $10 to $30 billion in the US and $75 billion worldwide [15].

4. DG Motivations

The major driving forces behind the recent revival of distributed generation are: the liberalization of the electricity markets, environmental concerns (GHG emissions) and the drawbacks in the conventional generation systems.

4.1 Liberalization of Electricity Markets

Liberalization of electricity market has allowed DG systems to enter the open markets in which they have the chance to sell power to a larger range of customers. Recently, DG has gained a lot of interest by electricity suppliers in the power industry, because they realize that DG can be the best solution to help covering the increased demand for electricity and take the advantages of the centralized power system generations deficiencies. Moreover, the smaller size of DGs, their quick installation and their lower cost compared with central power system, make them more flexible to respond to any change in the market conditions. In some areas it is uneconomical to build a centralized generation plant, geographical and operational flexibility of DGs make them more practical in such a case. One of the main derivers for moving toward DG technology in the US is the ability of DG to serve against the price fluctuations. Another factor is the reliability concerns which is represented by the power outages [1].

The liberalization of energy markets has an important role to enhance power reliability awareness among customers. The poor reliability of the centralized system has motivated companies to invest in DG units to achieve the required reliability for power grid. Figure 1 below shows how DG can obtain the cost reliability spectrum, that for a particular application high reliability and high cost or low reliability and low cost, DG can be obtained at both ends [17]. DG can support power quality in the system by prohibiting and mitigating system problems before they are detected by customer side. DG is used as back up generation with a space capacity to provide electricity to critical location, such as hospitals to prevent operational failures in cases of network problems.

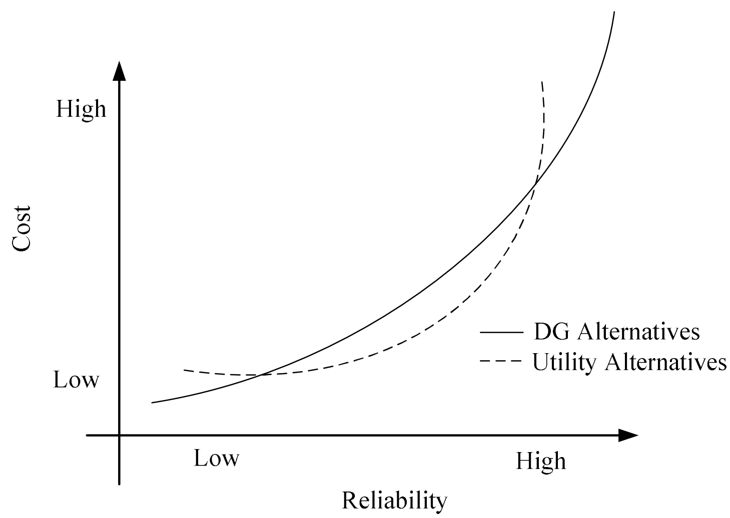

FIGURE. 1. Flexibility of cost and reliability for DG applications [17].

4.2 Environmental Concerns

The second motivator behind the revival of distributed generation is related to environmental policies. Environmental regulations force players in the electricity market to find suitable solutions for more efficient and cleaner energy. In addition, the target of most of the government policies is boosting the use of renewable sources of energy in many countries. Distributed generation has been able to achieve these targets through: Combined heat and power generation (CHP): Considering CHP instead of producing the heat in a separate boiler and generating electricity from the grid has a substantial role to reduce emissions and increase the energy efficiency. These units called cogeneration units which heavily depend on the distributed generation. Use of alternative fuel: distributed generation has been used to diversify away from coal, fuel, natural gas and nuclear fuel. Also, DG technologies allows taking the opportunities of using cheap fuel including burning landfills and collect their gases to generate electricity and biomass resources can also be used to produce local energy.

Furthermore, DG that uses renewable energy that is inherently produces no emissions. While DG technologies which based on using conventional fossil fuels can reduce the emissions through energy conversion processes, such as fuel cell, CO reservation, and production of gas [17].

4.3 Drawbacks of Central Generation (CG) Technology

Typically, Central Generations are located in remote areas, they required long transmission lines to deliver power to the load centers and customers, and this causes line losses in the transmitted electricity. Also, conversion losses resulted when the characteristics of the power flow is changed to meet the characteristics of the network [18] . These losses lead to high cost for transmission and distribution of electricity, which account for about 30% of average cost of the delivered electricity. Table 1 shows the total amount of losses in the US between 2002 and 2008 [19].

TABLE 1 Transmission and distribution losses for electricity in the U.S [19].

Date	Net Generation Billion kWh/ year	Transmission and distribution losses	Percentage %
2002	3858	248	6.4%
2003	3883	228	5.9%
2004	3971	266	6.7%
2005	4055	269	6.6%
2006	4065	266	6.5%
2007	4157	264	6.4%
2008	4115	241	5.9%

5. DG Technologies

Generally, DG technologies can be classified as renewable or non-renewable technologies. Renewable technologies include wind, solar (thermal or PV), geothermal or ocean. The non-renewable DG technologies are including internal combustion engines (ICE), combined cycles, combustion turbines, micro-turbines, and fuel cells. Energy storage uses combustion engines and turbines, micro-turbines, fuel cells and photovoltaic play an important role in DG applications compared with other available technologies [1].

5.1 Internal Combustion Engines (ICE):

This type of technology is widely spread and the most mature of the DG technologies worldwide. The most common available types of ICE are natural gas, and diesel fuel. This technology uses compressed air and fuel to produce mechanical power then this mechanical power is converted to electrical energy. The most attractive feature related to this type are: low capital costs, high efficiency (36-43% diesel fuel, 28-42% gas fuel), high reliability, quick start-up, high energy efficiency when combined with heat recovery systems (CHP) that increases the total electric and thermal efficiency up to 90%, and easy maintenance [1]. The capacity of ICE generation ranges from a few kilowatts to more than 30 MW. In the US, about 70% of engine has a range between 10 kW to 200 kW and the majorities are with capacity less than 1 MW. The total installed capacity in the US was accounted for around 52 GW in 2000 which represented about 7% of the total installed capacity in the country. Based on the size of the ICE DG units, the cost for diesel-fired units is almost 350-500 $/kW and for gas-fired ICE DG units is about 600-1000 $/kW [5]. Maintenance cost for diesel-fired ICE DG units ranges between 0.005-0.01 $/kWh and between 0.007-0.015 $/kWh for gas-fired ICE DG units [22] . In the US, the main applications of the ICE DG units are gas, electric and water utilities, manufacturing facilities, hospitals, educational and office buildings. However, as ICE DG units have large number of moving parts, this leads to high maintenance cost the highest among the DG technologies, poorly in terms of noise, as noise is low frequency and more difficult to control, and high emissions, which makes other technologies competitive with them.

5.2 Combustion Turbines (CT)

Gas turbines are vastly used for electricity generation in the globe. Typical applications for CT are in CHP with capacity between 500 kW to 25 MW. The typical efficiency is around 35% in the 5 MW ranges [2]. The efficiency of these turbines increases as the capacity increases. For example, for the units with 100kW the efficiency around to 16%, while the efficiency for units with 30 MW capacities about 45%. The efficiency may reach up to 55%, and these units mainly used in the central power system. The availability of the natural gas in most countries and its fixed price, make this type of units more attractive. Moreover, CT has low installation time and low capital cost, high efficiency, and significantly low NOx emissions (0.3-0.5 kg/MWh) [5]. However, the amount of CO2 emissions is very high about 580-680 kg/MWh. For installing a typical gas turbine, this needs initial cost around 650- 900 $/kW, and with a heat recovery unit the cost increases to1000-1200 $/kW. Average maintenance costs for combustion turbines are approximately 0.004-0.005 US$/kWh [22]. In the US a research program is conducting in order to obtain good efficiency for these units, reduce their sizes, lower their operational cost and improve their emission performance [5][21].

5.3 Microturbines (MC)

Microturbines can use air, natural gas and diesel to produce power. Their capacity varies between 25 kW to 500 kW, have an electrical efficiency of about 15% for unrecuperated type and between 20% and 30% for recuperated types. The efficiency of MC units becomes very high when they combined with CHP (85%). The main features of microturbines are the availability of the natural gas in many countries, small size, lightweight, less maintenance, easy to control their noise and low NOx emissions (0.1 kg/MWh). However, they have high CO2 emissions (720 kg/MWh) [5]. MC units can cover the base load of electricity, they are suitable for commercial building, and they also can be used as a standby generation unit and in hybrid electric vehicles [1]. The capital costs of installing MC is higher than installing IEC, it is evaluated between (700 and1100 $/kW) and the maintenance costs is between (0.005 and 0.016 $/kW) [21] [22] .

5.4 Fuel cells (FC)

Fuel cells can convert chemical energy of a fuel (natural gas or hydrogen) to electricity without combustion. The first applications for Fuel cell technologies were initially developed for space program applications, and then the transportation sector. Today, fuel cells are projected to have an important role in distributed generation applications. The main fuel used in fuel cells is hydrogen which is usually derived from natural gas, diesel, and landfill gas [5]. There are four main fuel cell technologies based on the type of the electrolyte material used. These include phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and proton exchange membrane fuel cells (PEMFC). The most commercialized technology among these types in power generating application is PAFC [21]. PAFC achieved about 80% of installed fuel cells capacity in the period between 1970 and 2003. PAFC generation units are now available in small sizes (3-5 kW) for residential applications and large size (100-250 kW) for commercial application. Various units with about 200 kW capacity which is good for distributed generation applications has been installed in the US, Europe, and Japan [23]. The main advantages for this technology are high electrical efficiencies (36 - 42%), very low noise and vibration, negligible emissions, compact size, and high reliability. While high capital cost and low energy density are the drawbacks for this technology. The capital cost of fuel cells plants reaches about $1.1 million, which very expensive compared with other types of DG technologies, units with 25 kW capacity cost about 4000 $/kW and 5500 $/kW for a 200-kW unit. Maintenance costs of fuel cells is objected to be

0.005-0.01 US$/kW [22][5]. In 2003, many countries, such as the US, Japan, the European Union, and Canada have supported fuel cells research programs to make this technology more applicable for commercial and residential applications in the current future.

5.5 Photovoltaic (PV)

Photovoltaic (PV) cells or solar cells technology can directly convert sunlight into electricity. So, the fuel for PV is the sunlight, this leads to no emission resulted from this technology. PV can be the best DG technology for residential and commercial applications. This technology available in small size (less than 10 kW), medium size (10-100 kW) and large size the utility scale (more than 100 kW) [22], PVs generate electricity with no noise, and quite operation since there is no moving parts are used. Additionally, PVs need low operation cost and maintenance cost which is around 1% of the capital cost annually. The main disadvantages face wider deployment of this technology is the high capital cost, the cost is estimated to be 6000-10000 $/kW, need large area to be installed, intermittency, as the power from the sun vary based on the weather conditions, and the need for storage devices. The price of electricity generated by PV systems could be as high as 0.30 $/kWh [22], and this price justified when transmission facilities are required to connect PV systems with remote areas. The efficiency of the commercially available PV modules ranges from about 5 to 15%, many efforts is exerting to improve PV efficiencies [22].

5.6 Wind Energy Technology

Wind turbines use the wind to produce electrical power. When wind blows it rotates the blades of the turbine to convert the kinetic energy of wind to mechanical energy, and then this mechanical energy rotates the rotor of the generator to generate electricity. Then the electricity is transmitted through underground cables to the load. The range of wind turbines size varies from less than 100kW to multi-MW [24]. Usually, several wind turbines are grouped together to form a wind farm. The capacity of wind farm ranging from a few MW to tens of MW. The large wind farms are often connected to the power grid. Small wind farms can be directly connected to the distribution units. The small-scale wind farms and individual wind turbines are typically known as distributed generation. Wind power is commercially available, produces no emissions; preserve land (no mining process). Moreover, the areas around wind turbine can be used for other purposes, such as farming and animal grazing. The main disadvantages for this technology are high capital cost, variable nature for wind, and bird mortality. The cost of wind turbines depends on the location and the type of the turbine. For example, the capital cost for 10 kW home wind turbine system costs about $25,000 - $35,000 [22] .Table 2 summarizes the main points for the above DG technologies.

TABLE 2 Summary for the DGs technologies

Technology	Capital cost \$/kW	O&M Cost \$/MWh	Capacity	NOx Kg/MWh	CO2 Kg/MWh	Main features
ICE diesel	350-500	5-10	a few kW -30 MW	10	650	-Low cost -High efficiency -High emission
ICE gas	600-1000	7-15	a few kW -30 MW	0.2-1	500-620	-Low cost -High efficiency -High emission
CT	650-900 (Depend on the size)	4-5	500 kW - 265 MW	0.3-0.5	580-680	-Low cost -Good efficiency -Readily available
MT	700-1100	5-16	25 kW - 500 kW	0.1	720	-Low noise -Small size -Long maintenance time
FC (PAFC)	4000-5500	5-10	5 kW - 250 kW	0.005-0.01	430-490	-Very low noise -Good efficiency -Compact size -No emission
PV	600-1000	1% of first investment	a few kW-10MW	0	0	-Clean -No noise -No emission -Expensive
Wind	2500-3500	--	100kW-multi-MW	0	0	-No emission -Clean -Expensive - Birds mortality

6. Economic Impact

6.1 Benefits

DG technologies have introduced many economic advantages to the systems and customers. Interconnecting DG to the system has contributed to increase the reliability of electricity, reduce losses that related to transmission and distribution systems. Additionally, DG has a big potential to cover the demand for higher power quality compared with the central grid. Due to the lack investment in the central power transmission systems which has led to many blackouts in many regions, DG is playing a significant part in generating power [25].

In rural areas where central grids are considered uneconomical, DG can be the most effective solution to supply power and creates more new jobs in these areas.
The sites of DG units eliminate the need for systems' transmission and distribution upgrading. As DG is located close to the load, this helps avoiding the cost related to building new lines or upgrading the system, moreover, reduces the losses and overloading in the system [25].
DG has a substantial role to stimulate competition in electricity supply, allowing customers without DG greater choice in suppliers [25] .
In the case of combined heat and power CHP where the efficiency is high and the capital cost is low, the total energy cost is cheaper than central systems.
DG utilities are small, which make them easy to build and more flexible in operation compared with conventional power plants.

6.2 Drawbacks

Although DGs have many economic advantages and cost reduction, there are some economic drawbacks compared with central power grids. Due to the economy of scale, DGs cost more per kilowatt to build than central power systems. The prices of fuel delivery (retail-market) are more expensive compared to the price for central generation (whole-sale). DGs have low fuel-conversion efficiencies compared with central plants unless they used with CHP. Moreover, subsidies are needed to make DG market competitive for system applications.

Renewable DG technologies, such as wind and PV are variable sources of energy, non-dispatchable as their energy share cannot be predicted, therefore back up generations are required to cover the power that not supplied by DG units. This increases total costs and may weaken the power system.

In the case of DGs connection, the local grid may need reinforcement. Based on the principle of economic the cost for upgrading the distribution system should be covered by the DG producers [25]. This increases the total investment cost of DGs.

Table 3 below gives cost comparison between the distributed generations and central generations

TABLE 3 CG and DG Cost Implication [2]

Component Cost	Centralized Generation (CG)	Distributed Generation (DG)
Cost of Capital	Lower Cost per unit	Higher cost per unit. Saved cost of system design due to reduced capacity. Saved cost of system design due to use of waste heat in cogeneration.
Fixed Operation and Maintenance Cost	Higher	Lower
Variable Operation and Maintenance Cost	Lower	Higher
Transmission	High voltage transmission is mandatory. High losses and transmission failure.	Only distribution line required. Reduced capital cost.

7. Technical impacts

Distribution systems in the conventional power grid are considered as passive elements, as they transfer the power in only one direction from the transmission system to the consumers, also their stability is associated with the stability of the transmission systems; they are stable if the transmission systems are stable. With the introducing of DGs, distribution systems have become active elements in the power system since they can generate and consume energy at load sides. From other side, the integration of DG has some technical impact in the power system in different aspects. It may affect the power flow, voltage stability, protection, and the power quality for both the electricity providers and end users. Below some of the technical impacts related to integrating DGs in the power system.

Power quality: The variable nature for wind and PV energies has direct effects on the quality of the energy. They may cause fluctuation, and flicker in the output voltages and powers [26], [27] resulting in violations of the power quality standards. Moreover, using power electronics converters (AC-DC, DC-AC) for the interconnection purposes produces harmonic distortion.

These harmonics have severe impact on the output power unless they are filtered. Also, the integration of DGs at some level may cause voltage drop in the system [28], [29] .

Power flow: Installation DGs influences the power flow in the network. It may change the power flow direction, decrease, or increase power losses and change the operation of other devices such as, voltage and reactive power compensation.

Protection system: The flow of power in the electrical system is unidirectional from the grid through the transmission system to the distribution systems then to the loads. High penetration of DGs may interface with the protection of the system. This interfacing may lead to over-current protection, instantaneous reclosure, ferro resonance, and ground faults [30][31].

8. Public Policy and Regulatory Impact

Public policies and regulations are different from place to place. Public policies and regulations also represent a main obstacle to the increased penetration for DG market and do not allow a smooth integration of new generation technologies. Difficulties in finding affordable connections to the power system, difficulties, and high cost for getting a declaration for a site, deficiency of national standards for interconnection additional costs for transaction, are some of the DG's regulatory barriers. Additionally, environmental standards have been intensified in some countries, with the same standards applied irrespective of the generator size.

It is important not to neglect the tax incentive impact on the development of DG technologies. In clean energy technologies, such as wind and PV, the facilities of construction and operation of DG are almost completely driven by tax incentives, which often significantly vary from one region another and from one year to another. These tax incentives mainly are provided at two levels: the first incentive is construction tax incentives, whether in the form of an upfront grant or accelerated depreciation schedules. The second one is operational tax incentives, generally in the form of revenue tax abatements [32].

9. Standards and Policies

9.1 Standards

Standards play an important role in addressing many of the needs for safety, power quality, lower cost, regulation, and education utilizing DG units. Standards have a key role in the prosperous future for DG deployment. IEEE Standards 1547 has developed into a series of documents that cover several DG technologies issues, most of which are also of interest to Canada. This series includes:

IEEE 1547 – Standard for Interconnecting Distributed Resources with Electric Power Systems [36] . This standard has been issued in 2003; it gives the basic information for interconnection of distributed resources up to 10MVA.

IEEE P1547.1- Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems [36]. This standard was released in 2005, gives a common set of test procedures to confirm the proportionality of interconnection system or component intended for use in the interconnection of distributed resources technologies with the power systems.

IEEE P1547.2 – Draft Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems [38] . This document includes technical depictions, applications instruction, and interconnection examples to promote the use of IEEE Standard 1547.

IEEE 1547.3 – Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems [39] . This standard was published in 2007.

IEEE P1547.4 – Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems [40] [68]. It gives alternative processes and practices for the design, operation, and integration of DG with power systems.

IEEE P1547.5 – Draft Technical Guidelines for Interconnection of Electric Power Sources Greater than 10MVA to the Power Transmission Grid, this guide will provide information regarding to design, construction, commissioning approval testing and maintenance demands with utilities more than 10MVA capacity to a power transmission grid [41].

IEEE P1547.6 – Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks. This standard provides information about interconnection distribution secondary system with distributed resources [41].

9.2 DG policies

The current regulatory framework supports DG through subsidies, incentives, and recognition of DG in procurement and planning processes. The main drivers for DG policies are support competition and economic efficiency, protect consumers from cost-shifting, preserve a viable utility privilege, protect the environment, and ensure safety and grid reliability. Table 4 summarizes the current regularity framework for DG [42].

TABLE 4 Summary of Current Regulatory Framework [42].

Regulatory Characteristics	Current Situation
Planning and Procurement Policy	State energy policy aims to incorporate DG into utility procurement and DG into distribution planning processes. Cogeneration has little consideration in utility procurement and planning processes.
Rate Structures	Energy prices are not transparent; inhibits customer response to actual costs. Current rate structure is based on controlled averaged pricing that does not include location and environmental externalities. It is difficult for DG to participate in wholesale power markets.
Incentives	Incentives (subsidies, tax credits, low interest loans) are in place to promote clean DG. Incentives are limited for cogeneration.
Rules and Regulations	Rules and regulations (e.g. interconnection rules, net metering, and exemptions from standby charges) have been changed to benefit some or all DG.

10. Case Study

Edmonton system has been adopted in this project to study the effectiveness of installed DG in the distribution system. The downtown Edmonton main area is being supplied by three substations, namely: Rossdale, Victoria and Garneau substations where the former is supplied from Bellamy substation [33]. Figure 2 shows the schematic diagram for the main substations of Edmonton downtown. In this study three combustion turbines (CTs) as distributed generations have been installed in Edmonton downtown system with total capacity 75MW (25 MW each). The main reasons behind using this type of DGs are that combustion turbines are very mature technology, gas combustion turbines are relatively inexpensive and readily available in most countries, their efficiencies in the range of 20 to 55%, and relatively have low environmental impact if control used. This case study will be divided into two parts; in the first part the price of generation electricity per kilowatt hour will be calculated and compared with the current price of the electricity generated from the utility. In the second one, the impact of combustion turbines on the transmission system losses will be studied.

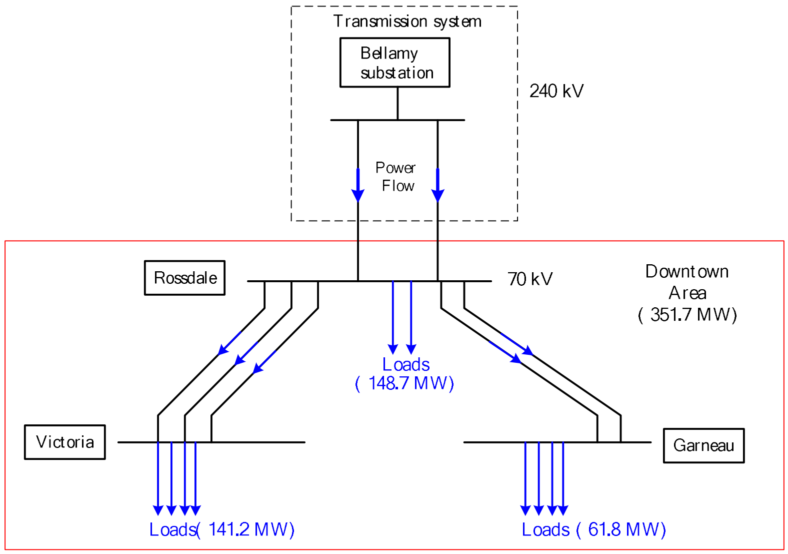

FIGURE. 2. Schematic diagram for the main substations in Downtown – Edmonton/Canada

The combustion turbine parameters that have been used in this study are shown in table 5 and the schematic diagram for the main substations in Downtown – Edmonton with the installation of DGs are shown in figure 3.

TABLE 5. The main parameters for the combustion turbine generation

DG Size	**25 MW**
Capital and installation costs	$1200/kW
O&M Cost Average Maintenance Costs	0.005 $/kWh
Efficiency	50%
Gas price	$6/MMBtu
Lifetime	20 years

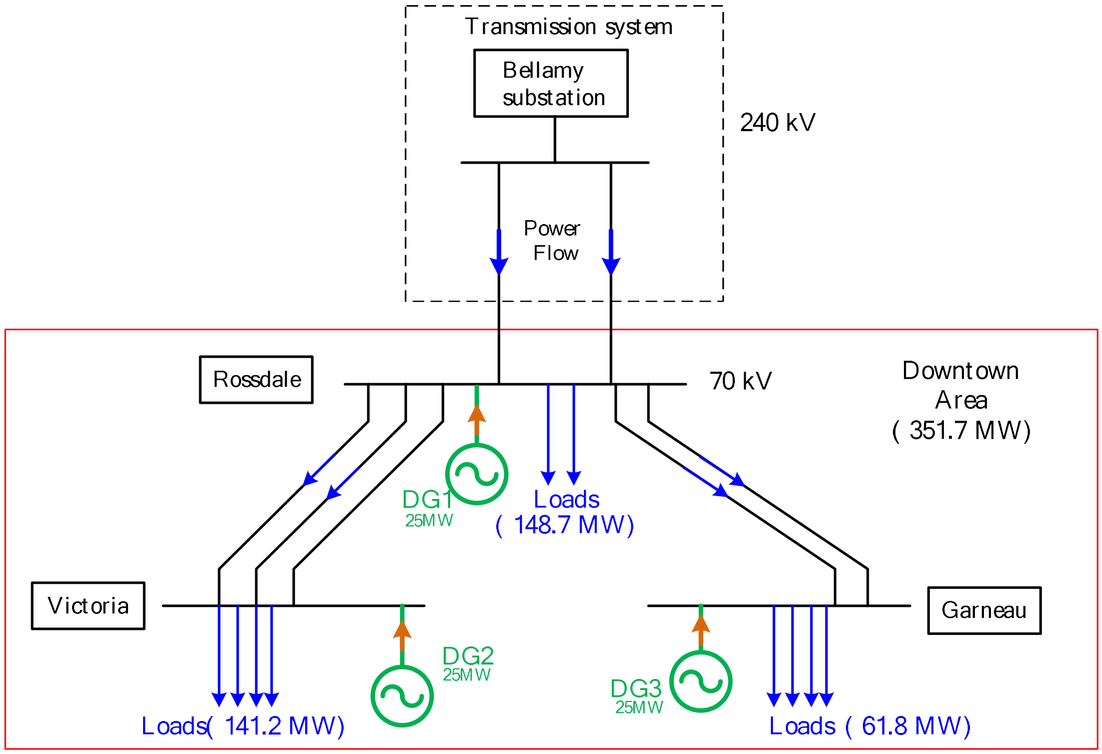

FIGURE. 3. Schematic diagram with the installed of DGs.

Calculations of Generating Electrical Energy

The cost of electricity (COE) is consisted as the sum of three components, capital and installation cost, operation and maintenance cost and fuel cost. The latter is the most significant part, it accounts for around 75% of the total cost.

$$COE(\$ / kWh) = C \& I + O \& M + F \qquad (1)$$

Where, C&I: Capital and installation cost, and O&M: Operation and maintenance cost, and F: Fuel cost.

Calculations of Capital cost

Capital and installation cost can be calculated by Equation (2)

$$C \& I(\$ / kWh) = \frac{TICperkW \times FCR}{CF \times 8760 \ hrs \ per \ year} \qquad (2)$$

Where, CF: the capacity factor and TIC: the total installed cost, and FCR: the fixed charge rate

CF is the capacity factor which is equal to the number of hours per year that the CTs will operate divided by the total number of hours per year it can be calculated as:

$$CF = \frac{Operating\ hrs\ per\ \ year}{8760\ hrs\ per\ year}$$

With 200 days per year → CF=0.55

Assuming FCR is equal to the annual amortized installed cost ($/yr) divided by the total installed cost ($):

$$FCR = \frac{TIC\ per\ kW\ /\ life\ time\ of\ \ unit}{TIC\ per\ kW} \equiv \frac{1}{life\ time\ of\ \ unit}$$

With 20 years lifetime → FCR =0.05

The total installed cost (TIC) for 25MW is $1200/kW (with heat recovery):

$$C\,\&\,I(\$\,/\,kWh) = \frac{\$1200\ /kW \times 0.05}{0.55 \times 8760\ hrs\ per\ year} = \$0.0124\,/\,kW$$

Calculations of Fuel cost

$$F(\$\,/\,kWh) = \frac{Fuel\,\mathrm{Pr}\,ice}{1000000\ Btu\ per\ MMBtu} \times HR$$

$$HR = \frac{3413\left(Btu/kWh\right)}{Efficiency} = \frac{3413}{0.904 \times .5} = 7550.8\,Btu/kWh$$

$$F(\$\,/\,kWh) = 0.0453\ kWh$$

Calculations of O&M cost

The average operation and maintenance cost is 0.005 $/kWh

The cost of electricity (COE)

By substituting the capital and installation cost, operation and maintenance cost and the fuel cost which we obtained from the above calculation in equation (1) we got:

$$COE(\$ / kWh) = \$0.0124 / kWh + 0.005\ kWh + 0.0453\ kWh = 0.0627 / kWh$$

According to electricity company, EPCOR, that responsible for the power system in Edmonton, the current electricity price is ¢8.561/kWh [34]. From the above results, it has been concluded that the price of the electricity generated from the CTs is less expensive than from the utility, therefore installation of CTs would be a cost-effective solution to meet the demand for electricity [35]. Also, it seems that CTs has a good motivation for the private and business owners to have their own generators [36-39].

Estimation of annual energy cost for the proposed Project

This part shows the annual energy cost for the proposed project and evaluates the financial investment in utilization CTs as a DG [40-42]. Using the previous equations, an excel sheet has been generated and the results are shown in table 5. The calculations are made based of the following assumptions:

All capital costs incurred in first year (which is reasonable for DG).

Discount rate is 7.5 %.

Labor cost is 2% of the revenue.

Capital cost allowance (CCA) is not considered (due to lack of information). Tax is not considered (due to lack of information) (i.e., gross revenue ($) is same as net revenue after tax ($)).

From the table we can answer the common questions in any project investment which is how long we would have to wait before we have earned more than we invested at the beginning, this value is obtained when the total cumulative net present value (NPV become positive [43] which is after 11 year (i.e. on the year 12 the project start earning money).

Loss Calculations. In this part of the study, Powerworld simulator [35] has been used to study the impact of distributed generation on the power losses in Edmonton downtown transmission system. Figure 4 shows the circuit that has been implemented by the Power World software for Edmonton-downtown with DGs implementation.

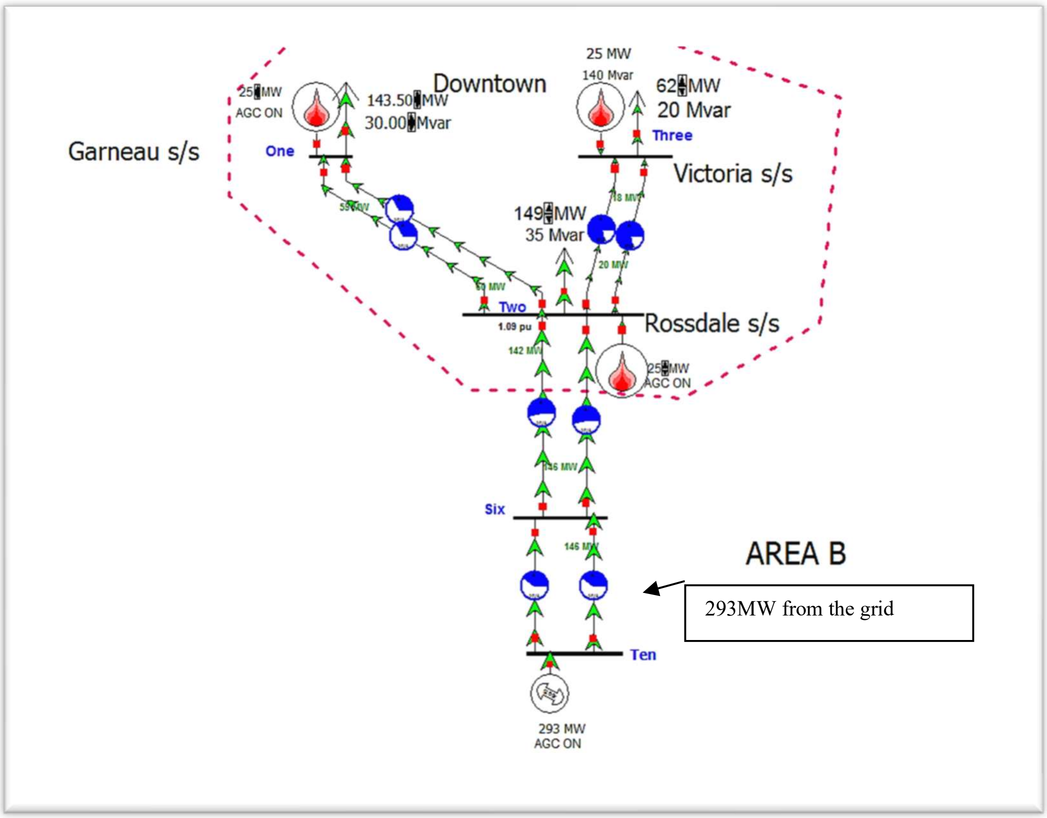

FIGURE. 4. Edmonton-downtown with DGs using the Power World software.

The amount of losses without DGs can be calculated as:

$$Power_{loss} = Power_{\sup ply} - Power_{load}$$

$$Power_{loss} = 369.5MW - 351.7MW$$
$$= 17.\ 58MW$$

While the losses with DGs:

$$Power_{loss} = 293MW - 351.7MW + 75MW$$
$$= 16.3MW$$

The cost of the power losses without using DGs and when DGs are in operation can be obtained as:

$$withoutDG \rightarrow Cost_{loss} = 17.\ 58MW \times 8760hrs \times \$85.61 / kMh = \$13.184M$$

$$with\ DG \rightarrow Cost_{loss} = 16.3MW \times 8760hrs \times \$85.61 / kMh = \$12.224M$$

The results revealed that using combustion turbines has reduced the amount of power losses resulted in the system. The result shows that when there is no distributed generation in operation the amount of power losses is about 17. 58 MW which corresponding to losses cost 10.16 ($M/year), while when the three (CTs) distributed generations are in operation this amount of losses is significantly decreased to become around 13.58 MW which corresponding to losses cost 10.16 ($M/year). Additionally, about M$ 0.96 can be saved in Edmonton downtown power system when these DGs are used.

11. Conclusion.

In this paper an overview about distributed generation (DG) systems has been provided. Distributed generation is generally perceived to be the technology that can help to achieve the environmental targets in some countries worldwide. It also can provide greater flexibility and energy efficiency to the end-users. Different definition based on the DG locations and capacities and the development of DG in the world were discussed in this work. Liberalization of electricity markets, environmental concerns, and the drawbacks of central power generation (CG) are the main drivers for using DG technologies, they were discussed in detail. A wide range of DG technologies, renewable (e.g., photovoltaic and wind) and non-renewable (e.g., internal combustion engines, combustion turbines, microturbines, and fuel cells) technologies were discussed in detail with their advantages, disadvantages, and capital and maintenance costs. Renewable energy resources are used to produce clean energy, while fossil fuels are used to obtain high efficiency using cogenerations or (CHP). Technical and economic impacts for DG also discussed. Additionally, the integration of DG in the grid introduces some technical, economic, environmental, and regulatory problems. Therefore, research is required to increase the benefits, decrease the drawbacks, and educate the public and network operators. Moreover, a case study was conducted to estimate the total costs of using combustion turbines in Edmonton downtown and to study the impact of DGs on the power losses. The results have proven that the total cost for CTs implementation is cheap, the project needs about 11 years to get revenue, and the losses in the power system decreases when DGs are in operations (which save money). The main challenges face distributed generations in Edmonton are lack of the national interconnection standards addressing safety, power quality and reliability for small DG systems and contractual barriers, such as liability insurance requirements, fees and charges, and extensive paperwork

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