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The Impacts of PV-Wind-Diesel-Electric Storage Hybrid System on the Reliability of a Power System

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Abstract

The integration of renewable energy resources into the conventional distribution system has changed the single power source to bidirectional and multiple power sources. This will increase the reliability of the system and as well as reducing the power outage that is associated with the radial distribution network. This paper presents an analytical method to investigate the impacts of using photovoltaic (PV), wind turbine generator (WTG), electric storage system (ESS) and diesel generator on the reliability of the distribution power system. The proposed technique is implemented on the feeder 1 of the Roy Billinton Test System (RBTS) distribution network to establish the fact that renewable energy resources can be utilized to improve the reliability of a power system. The results obtained from the study show that the application of DG technologies has achieved better results.

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Keywords: reliability; distribution system; failure rate; load points; frequency; duration.

1. Introduction

The high rate of world energy consumption caused by a growing population and global economic expansion coupled with a rapid industrialization has necessitated a massive investment in the reliable power supply. The recent advances in technology, deregulation of the power sector, high rate of consumer power demand, public concerns on depletion of fossil fuels and greenhouse gas (GHG) emissions have prompted many power utilities to integrate renewable energy resources into their networks as a measure to meet the power demand and at the same time to increase the reliability of their systems. Hence, the need for a reliable power system has always been very important because of the role electrical power plays in the economic, political and social well-being of a nation. The economic development of a nation entirely corresponds to the reliability of its power system since the greater part of its financial segment depends on this type of energy to boost up their economic activities.

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The function of an electric power system is to provide electricity to its customers at the minimum operating costs with an assurance of a reasonable quality and continuity at all-times. The reliability assessment of the distribution system is fashioned towards reduction of the frequency and duration of power interruption caused by the momentary and sustained outages while improving overall performance of the system. The continuity of power supply in the distribution system can be maintained with the integration of renewable energy resources and proper operation and maintenance (O&M) of an electric power system. This paper presents an analytical technique for the evaluation of reliability indices and power interruption costs that are associated with the distribution networks by using modified RBTS system. The results obtained from this technique show that the distributed generator (DG) technologies can be utilized to improve the reliability of a power system.

Nomenclature

P_{pv}	Power output of the PV system (kW)	n_{pvg}	PV efficiency
k_e	Cost of energy not supplied (CENS)	A_{pvg}	PV array area (m^2)
P_n	Nominal power generated by diesel generator (kW)	P_i	Average load (MW)
I_{pvg}	Solar irradiation of the PV array (kWh/m^2)	ρ_{wind}	Air density (kg/m^3)
C_{wind}	Coefficient of the wind turbine	Δt	Time step
η_d	Battery efficiency during discharging	V_{wind}	Wind velocity (m/s)
η_c	Battery efficiency during charging	η_{gb}	Efficiency of generator & gear box
P_{gen}	Output power of the diesel generator (kW)	η_{gen}	Efficiency of the diesel generator
PF_x, PF_y and PF_z	Power flow in the line sections x, y and z	N_{gen}	Number of diesel generator

2. Renewable energy resources and their applications

Renewable resources are widely accepted as the environmentally friendly resources that can be used continuously without replenishing and can be replaced naturally. The renewable energy DG technologies have offered the best alternative to reduce over dependence on the fossil fuels, improve the reliability of a power system and reduce GHG emissions. The renewable energy resources have witnessed a rapid growth in recent years due to public awareness of environmental impacts of using conventional power units. The rapid growth of the renewable energy resources is also attributed to the policies that have been introduced in many countries to increase the integration of the renewable energy units in the power systems, i.e. renewable portfolio standard (RPS), fixed feed in tariffs and renewable energy obligation. The DG technologies are the power generating units that are installed very close to the consumer load points to produce electricity [1]. The DG technologies can be used as standby, peak shaving and base load units for consumers' power generation.

2.1. DG technologies model

The DG technologies play a vital role in the availability of power supply because of their cost effectiveness to meet the consumers' load requirements. This section briefly presents modeling of DG technologies such as PV, WTG, ESS and diesel generator.

2.1.1 PV system model

The power output of a PV system depends on the ambient temperature and the solar irradiance of the location where PV modules are installed. The output power of the PV system can be expressed as [2]:

$$P_{pv} = n_{pvg}\, A_{pvg}\, I_{pvg} \tag{1}$$

2.1.2 WTG model

The output power of WTG (P_{wind}) depends on the rated speed, rated power, cut-in speed, cut-out speed, swept area and tower height. The electrical power output of the WTG can be estimated by using wind speed data of the location where WTG is installed. The output power of the WTG can be expressed as [3]:

$$P_{wind} = \frac{1}{2}\eta_{gb}\rho_{wind}\, C_{wind}\, \mathrm{A}\, V_{wind}^{3} \tag{2}$$

2.1.3 ESS model

The output power of the PV and WTG is intermittent owing to the stochastic characteristics of the local renewable energy resources [4]. This has prompted ESS units to be strategically integrated into a hybrid power system so that it will balance the shortage of power when local renewable resources are not sufficient to operate the PV and WTG systems. The output power of WTG and PV systems at a particular time and location determines the state of charge (SOC) of the battery storage. The state of charge of a battery can be expressed as:

$$SOC_{(k+1)} = \begin{cases} SOC_k - \eta_c P_b[k]\Delta t \\ SOC_k - \dfrac{1}{\eta_d} P_b[k]\Delta t \end{cases} \tag{3}$$

2.1.4 Diesel generator model

Diesel generator is incorporated into the distribution system to act as a standby or emergency unit in the absence of power generation from the PV, WTG and ESS storage units. The integration of diesel generator is attributed to the following features: modular size, quick start up and high efficiency. The operation of a diesel generator is limited owing to high fuel consumption and greenhouse gas (GHG) emissions [5]. The output power of the diesel generator can be expressed as:

$$P_{gen} = P_n * N_{gen} * \eta_{gen} \tag{4}$$

3. Problem formulation

The main objective of this paper is to minimize the cost that is associated with the power outage in the distribution system while satisfying the system requirements. The impacts of the renewable energy resources on the reliability of a power system can be investigated by optimising the main objective function of this paper which is presented as:

$$\mathrm{F} = \min \sum_{i=1}^{n} (k_e EENS + ECOST)\ \$/yr \tag{5}$$

3.1. Reliability indices

Reliability is the probability that a power system will perform its function adequately without any failure within a stipulated period when subjected to normal operating conditions. The impacts of the DG technologies in a power system can be investigated by using the following reliability indices [1, 6]:

i. Expected energy not supplied (EENS) index at load point is the total energy that is not delivered at the system load points as presented in Fig. 1.

$$\text{EENS} = P_i U_i \text{ (MWhr/yr)} = \sum_{i=0}^{n} \lambda_i r_i L_i \quad (6)$$

$$= \lambda_x r_x L_x + (\lambda_x r_x + \lambda_y r_y) L_y + (\lambda_x r_x + \lambda_y r_y + \lambda_z r_z) L_z \quad (7)$$

$$= (L_x + L_y + L_z)\lambda_x r_x + (L_x + L_y)\lambda_y r_y + L_z \lambda_z r_z \quad (8)$$

$$= PF_x \lambda_x r_x + PF_y \lambda_y r_y + PF_z \lambda_z r_z = \sum_{i=0}^{n} \lambda_i r_i PF_i \quad (9)$$

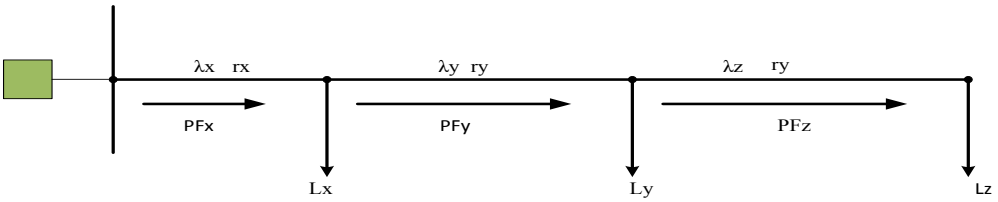

Fig.1: A distribution system with the section lines

ii. Expected interruption cost (ECOST) index is the cost of not supplying the consumers at the load points due to the power outage that is associated with faulty components in a power system. ECOST depends on the characteristics of consumers.

$$\text{ECOST} = P_i \sum N_e f_{r,j} \lambda_i \text{ (k\$/yr.)} \quad (10)$$

$$= P_x N_e f_{x,j} \lambda_x + P_y N_e f_{y,j} \lambda_y + P_z N_e f_{z,j} \lambda_z \quad (11)$$

4. Application of DG technologies in a power system

A modified RBTS distribution system is selected to investigate the impacts of using renewable energy resources in a power system. The system consists of 7 load points, 11 transformers and 15 circuit breakers as presented in Fig. 2. The feeder and customer details, failure rates and repair rates of the major components of the system can be found in [7]. The rated values of PV, WTG, ESS and diesel generator are 2 MW, 2 MW, 0.5 MW and 4 MW respectively. These generating units are integrated into the existing distribution system to improve the reliability of the consumer power supply. The present value of CENS for South African power system which is estimated to be $ 5.5/ kWh or R75/kWh is used in this study. The impacts of DG technologies on the distribution system can be investigated by using the following case studies:

Case study 1: Conventional power system without the diesel generator, PV, WTG and ESS units
Case study 2: Only diesel generator without PV, WTG and ESS units
Case study 3: Conventional power system with PV unit
Case study 4: Conventional power system with PV and ESS units

Case study 5: Conventional power system with PV, WTG and ESS units

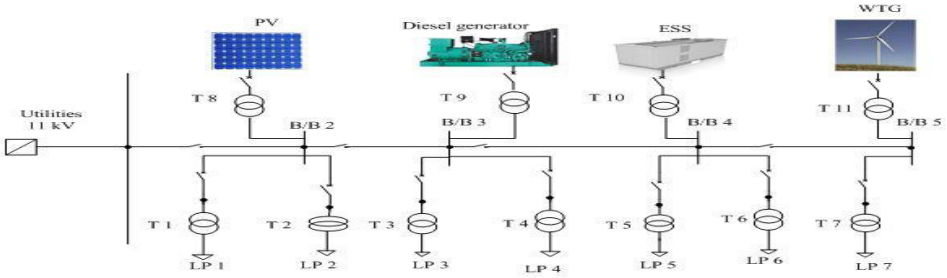

Fig. 2. Feeder 1 of modified RBTS distribution system

5. Results and discussion

The results obtained from the simulation show that the reliability of the radial system is seriously affected by the circuit length and distribution equipment failure. DG technologies have been integrated into the network as a measure to overcome the trend of economic impacts of power interruption as presented in Table 1 and Fig. 3. This has resulted in a reduction of the amount of outages and duration and frequency of power interruption experience by the consumers at the load points. The impacts of each case study as can be seen in Fig. 3 has established the fact that DG technologies can be used to reduce the power outage duration and frequency that should have impaired electricity supply to some consumers.

Table 1: PV-Wind-Diesel-Electric Storage Hybrid System

Case studies	1	2	3	4	5
System EENS (MWhr / yr)	125.977	14.052	7.621	6.567	6.388
System ECOST ($/yr)	708,006.60	72,677.72	37,837.79	32,545.55	31,043.39
Total outage cost ($/yr)	1400880.1	149963.72	79753.29	68664.05	66177.39
Optimized cost ($/yr)	-	1250916.38	1321126.81	1332216.05	1334702.71
Optimized cost (%)	-	89.29	94.31	95.10	95.28

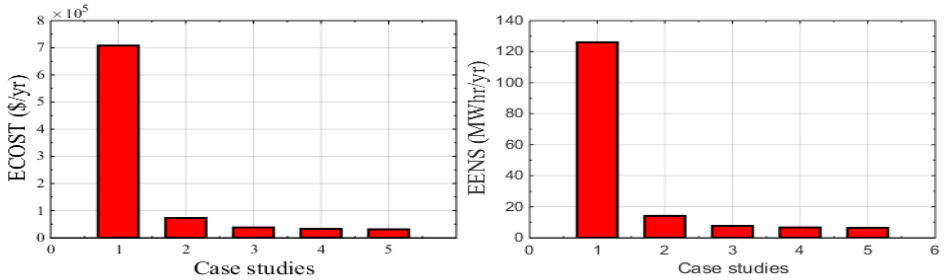

Fig.3: Impacts of the DG technologies on reliability of a power system

Case study 1: The relaibitity assessment of a conventional power system is carried out without application of the diesel generator, renewable resources and ESS units. The values of the system's EENS and ECOST are observed to be very high due to the duration of the power outage experienced by the consumers.

Case study 2: The integration of the diesel generator has improved the cost saving by 89.29% as presented in Table 1 and Fig. 3. The results obtained from the integration of diesel generator into the system show that reilaibity of a power system can be improved with penetration of the diesel generator. However, the benefit is limited owing to the high cost of fossil fuels and GHG emisions.

Case study 3: The integration of the PV unit into the system has further improved the reliability of the system by 94.31% just as it reflected in Table 1 and Fig. 3. This will ultimately reduce the frequency and duration of the power outage at the consumer load points. The results obtained from this case study as can be seen in Table 1 show that the ECOST and EENS decrease rapidly with the incorporation of PV into the system.

Case study 4: The increase in penetration of PV and ESS units into the conventional power system has a significant improvement in the reliability of the distribution power system with the increament saving of 95.10%. This has further enhanced the power system reliability, reduced the power outage at the load points and increased the efficiency of the power system.

Case study 5: The results obtained from this case study can be seen from the Table 1 and Fig. 3 where it is vividly proved that there is further reduction in the cost that is associated with the system power outage. About 95.28% is saved with the application of renewable energy and ESS units. The results obtained from the simulations have indicated that the reliability of a power system can be improved with additional energy resources.

6. Conclusions

The results obtained from this study have established the fact that the optimal solution to reduce the power interruption and the costs that are related to the improper management of power outage in the distribution system can be achieved with the integration of PV, WTG, diesel generator and ESS into a power system. It is expected that improvement in the reliability of the distribution system will enhance the performance and efficiency of a power system. The future work will elaborate how renewable energy resources can be utilized to optimize the reliability, fuel cost, emission cost and maintenance cost of a power system.

References

[1] Adefarati T, Bansal RC. Integration of renewable distributed generators into the distribution system: a review", IET-*Renewable Power Generation, 2016*; 10 (7), 873-884.
[2] Alkuhayli AA, Chowdhury BH. Reliability evaluation of distribution systems containing renewable distributed generation. *North American Power Symposium (NAPS), 2012*; p. 1–6.
[3] Bansal RC, Bhatti TS. Small signal analysis of isolated hybrid power systems: reactive power and frequency control analysis. *Oxford UK: Alpha Science International* 2008.
[4] Khare R, Kumar Y. A novel hybrid MOL–TLBO optimized techno-economic-socio analysis of renewable energy mix in island mode. *Applied Soft Computing* 2016; (43):187-198.
[5] Liu X, Bansal RC. Thermal power plants: modelling, control and efficiency improvement. *New York, USA: CRC Press* 2016.
[6] Čepin M, *Assessment of power system reliability methods and applications*. London: Springer-Verlag Limited 2011.
[7] Allan RN, Billinton R, Sjarief L, Goel L, So KS. A reliability test system for educational purposes—basic distribution system data and results, *IEEE Trans. Power System, 1991;* 6 (2): 813–820.

Biography

Prof. Ramesh Bansal has over 25 years of experience and currently he is Professor and group head (Power) in the Department of EEC Engineering at the University of Pretoria. He has published over 250 papers. Prof. Bansal is an Editor of IET-RPG & Electric Power Components and Systems. He is a Fellow, and CEngg IET-UK, Fellow Engineers Australia and Institution of Engineers (India) and Senior Member-IEEE.