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Reliability Assessment of Distribution Network Considering Fuel Cell (F.C)

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Abstract: Using fuel cells as energy sources change the reliability of distribution power systems. This paper studies the effects of fuel cells on the reliability of a distribution power system. The method is based on the value-based method for a FC farms located in Iran. The obtained results show that when the fuel cell number changes, then the reliability of the power system varies non-linear. Therefore, the optimal number of the fuel cell for maximum reliability can be obtained by using value-based method.

Key words: fuel cell, Reliability, Distributed Power Generation, Distribution Power System.

INTRODUCTION

In a DG-enhanced feeder, power flow is not unidirectional and conventional protection logic needs to be adjusted accordingly. A faulted branch may be energized from both sides, and several protection devices may need to operate in order to completely interrupt the fault current. Various protection strategies, using local or SCADA measurements, may be utilized. As one can see, the locations of protection devices and distributed generators are highly inter-dependent. Properly placed distributed generators such as fuel cell are crucial to achieve the optimal design of a DG-enhanced distribution network in terms of system reliability, power quality and investment costs.

The optimum placement of switches in conventional distribution networks have been discussed in many papers with different optimizing algorithms such as genetic algorithm, bellman method, particle swarm optimization, etc. In these papers various objective functions are also presented with combinations of costs and reliability indices.

Chen has carried out optimum switch placement with QEA-based algorithm to improve customer service reliability A new composite objective function of investment cost and reliability on optimum placement of line switches is presented in Ref.2.The allocation of switches by using of PSO algorithm with composite objective function of system costs and ECOST has been solved in Ref.3. Billinton and Jonnavithula have discussed using of simulated annealing optimizing algorithm. In their method they have evaluated the harm of load shedding and effect of switches on reliability improvement.

In another research, Celli and Pilo have discussed the switch placement problem by using of Bellman optimization algorithm.Teng and Lu have worked on reconfiguration of switch placement in Distribution networks for reliability improvements.

In all of these papers, the effect of FCs has not been seen. After appearance of FC on distribution network and opportunity of islanding application of FCs, the optimum placement of switches would be affected with placement of FCs.

The value-based method is one of the popular techniques for dealing with the power systems reliability. There have been proposed many studies associated with the value-based techniques, but most of them deal with radial topologies. When FC is connected to a radial distribution power system, then the network changes to non-radial system. Because, in this case, the distribution power systems are fed from two sides, on one side there are FCs and on the other side there are conventional generation (CG) sources. In this paper the value-based technique based on the cost/worth concept is used for evaluating the effects of adding FCs on the reliability of power systems. The indices such as EENS (Expected Energy Not Supplied), Ecost (Expected Interruption Cost), FGIEB (Fuel cell Generation Interrupted Energy Benefit), FGICB (Fuel cell Generation Interrupted Cost Benefit), ENCG (Equivalent Number of Generators) and ECGC (Equivalent Conventional Generation Cost) are used. In addition, the optimal number of FCs based on the value of FGIEB will be obtained.

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Hybrid Power System:

Fig.1 shows the block diagram of the hybrid power system proposed in this study that connected to main grid in Point Common Coupling (PCC).

The considered structure for HRES in this study is a kind of renewable energy sources, includes FC and battery bank.

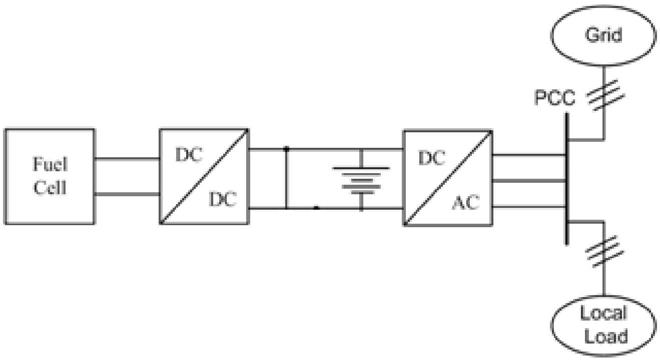

Fig. 1: The block diagram of the hybrid power system considering Fuel cell.

Fuel Cell Specifications:

Recently fuel cells have been employed for generating electrical power. However, because of their limited inherent characteristics such as a long start-up time and poor response to instantaneous power demands, energy storages have been combined with fuel cells to achieve the high power density with the high energy density of fuel cells.

However photovoltaic power systems are, dependent on climatic conditions and their output depends on the time of year, time of day and the amount of clouds. Therefore hybridization of fuel cell with FC will form a very reliable distributed generation where the fuel cell acts as back up during low FC output. The slow dynamics of the fuel cell can be compensated by adding battery energy storage. If a fuel cell was connected to a load that increase step by step, it would provide the current, but the voltage could instantaneously drop off the V-I curve and the fuel cell would take several seconds until it begins feeding the required power. In the mean time the fuel cell may be starved of fuel which is not good for the electrocatalyst shortening its life. Therefore, the fuel cell should be operated under controlled steady state regime during which the battery is providing the required power. In this paper a distributed power generation system based on hybrid fuel cell/battery for providing a part of active and reactive power for a load that is connected to local grid is presented. For loads beyond the maximum capacity of the hybrid power system and inverter, the main grid supplies the rest of the local power demand. This helps to relieve transmission line congestion problem by producing most of the local demand locally. It also can reduce transmission line losses especially for loads very far from the utility grid. The hybrid power system can also provide ancillary service to the utility by allowing the grid operates at unity power factor at the point of common coupling.

The certainty of meeting load demands at all times is greatly enhanced by the hybrid system using more than one power source.For the remote and isolated network areas fuel cell is the best option to provide the network demand. Fuel cells are static energy conversion devices that convert the chemical energy of fuel directly into electrical energy. They show great promise to be an important DG source of the future due to their many advantages, such as high efficiency, zero or low emission (of pollutant gases), and flexible modular structure. Fig.2 shows the power generation versus fuel consumption for the fuel cell.

The technical data of FC includes average of annual radiation for Photovoltaic arrays, average of wind speed, lifetime of each energy sources, DG capacity and economical specifications such as, interest rate, capital recovery factor, annualized capital cost, annualized replacement cost and cost coefficients of each DGs. In order to accommodate the varieties of DG units, assumptions are made on the basis of the cost characteristics of central generation. The cost comparison among the various units is made as per the incremental cost. Incremental cost is a function of power output of the unit where slope indicates cost to produce incremental quantity and intercept indicates no load cost. Other conditions remaining the same, the lesser the slope, the

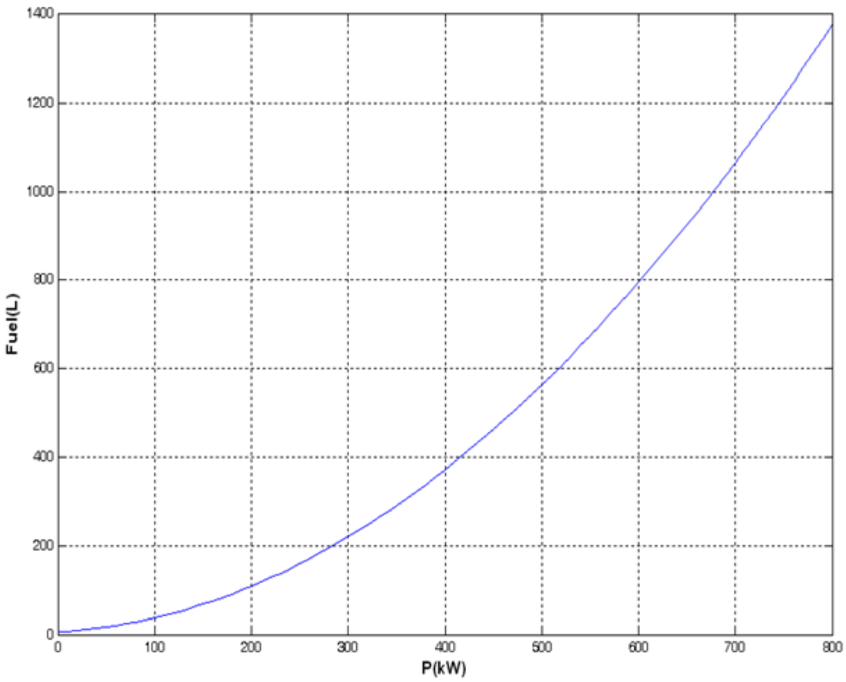

Fig. 2: Fuel-Power curve for the fuel cell.

lower the incremental cost and higher the penetration. The crossing over of two different incremental cost characteristics reveals that operational cost effectiveness depends on power output. The crossing over is determined by no load cost and slope of the curve.

The cost characteristic of DG units considered in test system is shown in Figs.3.

Also the capital cost and replacement cost characteristics of various DGs considered in this study is shown.

The cost characteristics considered have wide variety of slopes and accordingly, intersection at several points. Hence, the comparative study of operational cost among the units relies on power output.

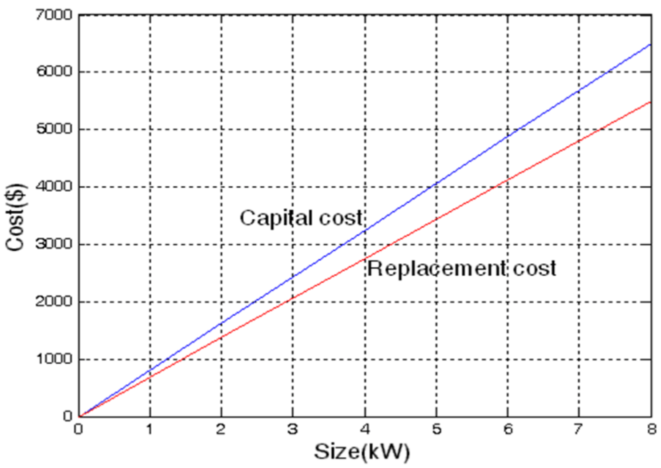

Fig. 3: Cost characteristic of FC.

Economic Parameters in FC:

The economic viability of a proposed plant is affected by several factors that contribute to the expected profitability. In the economical analysis, all costs such as Capital cost, Replacement cost, Operation and maintenance cost and Fuel cost (just for Fuel Cell) must be considered. To achieve optimal design of a hybrid power system, total annualized costs are defined as follow:

Replacement Cost Duration:

The replacement cost duration is given by:

$$R_{rep} = R_{comp}.INT(\frac{R_{proj}}{R_{comp}}) \tag{1}$$

Where:
Rcomp = lifetime of the component

Remaining Life of the Component:

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \tag{2}$$

Annualized Capital Cost:

The annualized capital cost is given by:

$$C_{acap} = C_{cap}.CRF(i, R_{proj}) \tag{3}$$

Where, Ccap is initial capital cost.

Annualized Replacement Cost:

The annualized replacement cost is given by:

$$C_{arep} = C_{rep}\{f_{rep}.SFF(i, R_{comp}) - (\frac{R_{rem}}{R_{comp}}).SFF(i, R_{proj})\} \tag{4}$$

Where, Crep is the cost of replacing a component at the end of its lifetime.
frep is a factor arising because the component life time can be different from the project lifetime, is given by:

$$f_{rep} = \begin{cases} \frac{CRF(i, R_{proj})}{CRF(i, R_{rep})}; R_{rep} > 0 \\ 0; R_{rep} < 0 \end{cases} \tag{5}$$

Value-Based Method Indices:

The value-based method evaluates the reliability cost associated with different power system configurations. The reliability cost is the capital cost of the utility invested to improve reliability for consumers. It is usually difficult to evaluate the reliability cost directly; hence it is obtained by calculating some indices .The most popular using indices are explained as fallow:

$$FGIEB = \frac{EENS_{bFC} - EENS_{aFC}}{Incremental\ \ FC\,Generation\ \ Capacity + Costs\,of\ \ fuel\ \ related\ to\,unit\ Power\ Generated} \tag{6}$$

$$FGICB = \frac{ECOST_{bFC} - ECOST_{aFC}}{Incremental\ \ FC\,Generation\ \ Capacity + Costs\,of\ \ fuel\ \ related\ to\,unit\ Power\ Generated} \tag{7}$$

$$ENCG = \frac{RNCG}{RNFG} \tag{8}$$

$$ECGC = \frac{RCCG}{RCFG} \quad (9)$$

Where:
$EENS_{bfc}$: Expected Energy Not Supplied before adding FCs
$EENS_{afc}$: Expected Energy Not Supplied after adding FCs
$ECOST_{bfc}$: Expected Interrupted Cost before adding FCs
$ECOST_{afc}$: Expected Interrupted Cost after adding FCs
FGIEB: Fuel cell Generation Interrupted Energy Benefit
FGICB: Fuel cell Generation Interrupted Cost Benefit
ENCG: Equivalent Number of Conventional Generation Unit
ECGC: Equivalent Conventional Generation Capacity
RNCG: Required Number of Conventional Generation Unit
RCCG: Required Capacity of Conventional Generation Unit
RNFG: Required Number of Fuel cell Generation Unit
RCFG: Required Capacity of Fuel cell Generation Unit

In this paper, the indices EENS, Ecost, FGIEB, RNCG, RNSTG and ENCG are only used for evaluating the reliability of the distribution power systems.

Simulation and Discussion:

The system under consideration is the part of a distribution power system Iran as shown in Fig.4.

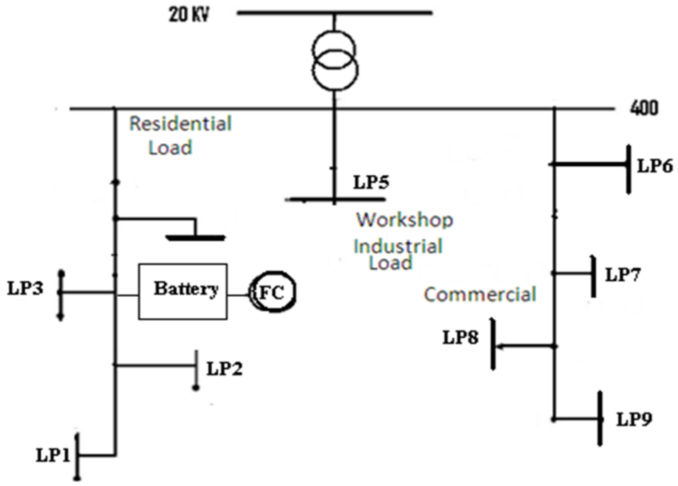

Fig. 4: Test distribution network.

As can be seen, the network is supplied by CG units on the grid side and FCs on the opposite side of the network. The size of FCs is more than the total loads and therefore, some part of generated energy by FCs could be exported to the grid. The load points are indicated by LP1 to LP9 with the total amount of 8.4 MW. LP1 to LP4 are residential load points, LP5 is industrial loads and LP6 to LP9 are commercial load points.

In this simulation, three different cases have been selected for analyzing the reliability of the network.
Case 1 No FCs are connected to the network.
Case 2 10 MW FCs are connected to the network.
Case 3 10 MW Conventional Generation unit is used instead of 10 MW FCs.

In each case, the reliability of the network is obtained by calculating the introduce indices. For this purpose, the fallowing procedures have been used.

- Determination of fail operation probability of each section of the network and FCs. (The probabilities of fail operation of FCs are given 4%)
- Determination of loss of power cost for each load.(10 $ per MW is considered as the penalty for commercial consumers and 50$ per MW is used as the penalty for industrial consumers. The load points 1, 2 and 3 are considered as the commercial consumers and the load points 4, 5 and 6 are industrial consumers).

- Determination of EENS for each load points before and after adding FCs.
- Determination of Ecost before and after adding FCs.
- Determination of indices values.

7. Results of Simulations:

The MATLAB software is used for obtained results. The Figure 5 and Figure 6 show the simulation results for each three cases introduced in section V. Figure 5 shows that the EENS value for the case 1 is higher than the values for other cases. When 10 MW FCs are added to the network, then the value of EENS reduces. The minimum of EENS will be obtained when a 10 MW conventional energy source is used instead of the FCs. Furthermore, the EENS values have linear relation with the load points' power. For example, the EENS value of LP5 is higher than the EENS value of LP6.

Figure 6 shows the Ecost values for each load points. As can be seen, the variations of Ecost values are similar to the EENS values in Figure 3. Because, the relation between Ecost and EENS is:

$$E\cos t_i = EENS_i \times COST_i \qquad (10)$$

Where
COSTi: The loss of power cost of the load point i.

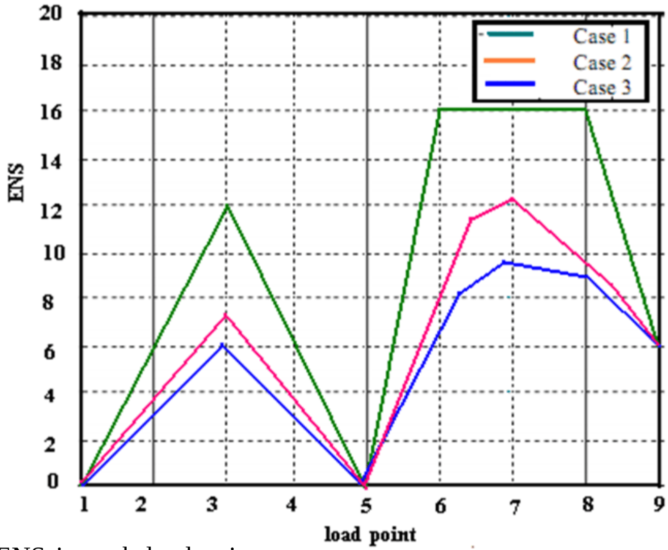

Fig. 5: Variations of EENS in each load point.

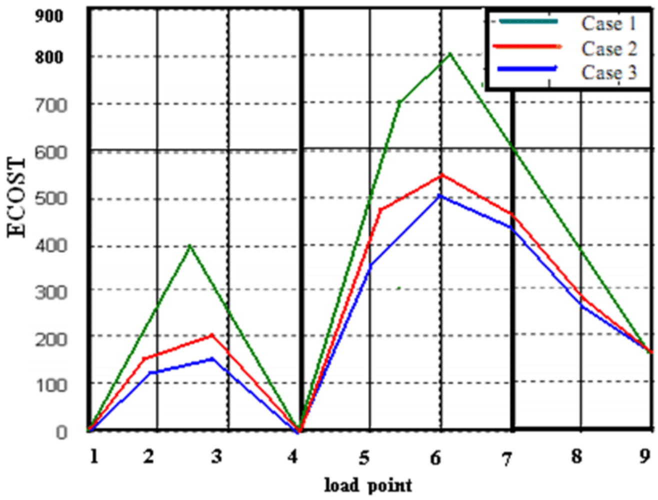

Fig. 6: Variations of ECOST in each load point.

As stated before, it is considered that 10 $ per MW is the loss of power cost for load points 1, 2, 3 and 50$ per is assumed for load points 4, 5 and 6. Figure 3 and Figure 4 show that the reliability of the power system will be changed. For obtaining the reliability of the network, it is necessary to calculate the EENS and Ecost of the network. The expressions (11) and (12) explain the EENS and Ecost relations.

$$EENS = \sum_{i=1}^{i=9} EENS_i \tag{11}$$

$$E\cos t = \sum_{i=1}^{i=9} E\cos t_i \tag{12}$$

The values of EENS and Ecost for the entire network in each three cases are shown in Table 1.

Table 1: EENS and ECOST of the Network

	Case 1	Case 2	Case 3
EENS (MWh/yr)	26.20	23.34	18.24
ECOST ($/yr)	1672.3	1457.2	821.87

Table 1 shows that the EENS value decreases when FCs and conventional energy source are added to the network. By adding FCs, the EENS value reduces by 10% percent, while adding conventional energy source decreases the EENS by 69%. It is evident that adding conventional energy sources has better effect than FCs on the reliability of the power system. The value Ecost also reduces when FCs are added to the network. For example, the difference of Ecost value between the case 1 and the case 2 is about 20%. In addition, the annual outage of load points in three cases are studied and shown in Table 2.

Table 2: Calculated Annual Outage of Load Points (Hours/Years).

Load Point	Case 1	Case 2	Case 3
LP1	0.62	0.20	0.17
LP2	4.30	0.98	0.90
LP3	0.20	0.89	0.86
LP4	12.7	9.90	9.10
LP5	13.6	9.80	9.45
LP6	2.24	2.00	1.34
LP7	4.30	1.80	1.45
LP8	2.20	0.12	0.10
LP9	3.10	1.20	1.16

As the third column of Table 2 shows, the annual outage of load points where are near FCs have been decreased, but the related values for load points are far from FCs have less variations. For example, the annual outage of LP1 has decreased from 0.62 to 0.22, but the value of LP6 has remained at 2.24. Better figure of the reliability will be obtained if the FGIEB index is calculated. Figure 7 shows the variations of FGIEB when the number of FC changes. In this case, each FC has 1 MW capacity.

Figure 7 shows that better benefit obtained when the number of FCs is 3. For calculating ENCG, it is required to calculate the Ecost variation of the network when the number of FCs and conventional generation unit change. The variation of Ecost has been shown in Figure 8. Figure 8 shows that for a specific Ecost, for example near 1300 $/Year, The required number of FC is 10 (RNFG=10) and for the same Ecost the required number of conventional generation unit is 4.8. Therefore, ENCG is 0.48.

In other words, the Ecost of 10 unit of FC is equal with the Ecost of 4.8 conventional generation unit.

- Case 1 No FCs are connected to the network.
- Case 2 10 MW FCs are connected to the network.
- Case 310 MW Conventional Generation unit is used instead of 10 MW FCs.

In each case, the reliability of the network is obtained by calculating the introduce indices. For this purpose, the fallowing procedures have been used.

- Determination of fail operation probability of each section of the network and FCs.
  (The probability of fail operation of FCs are given 7%)
- Determination of loss of power cost for each load.
  (10 $ per MW is considered as the penalty for commercial consumers and 50$ per MW is used as the penalty for industrial consumers. The load points 1, 2 and 3 are considered as the commercial consumers and the load points 4, 5 and 6 are industrial consumers).

- Determination of EENS for each load points before and after adding FCs.
- Determination of Ecost before and after adding FCs.
- Determination of indices values.

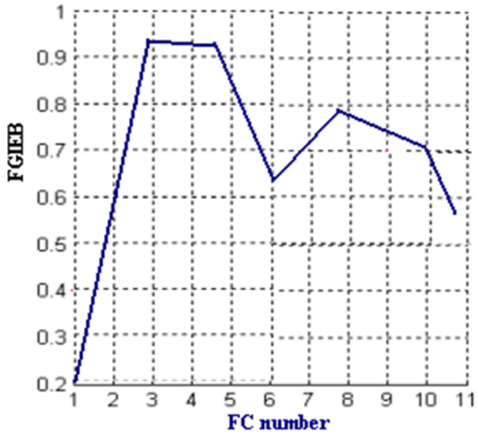

Fig. 7: Variations of FGIEB versus the number of FC.

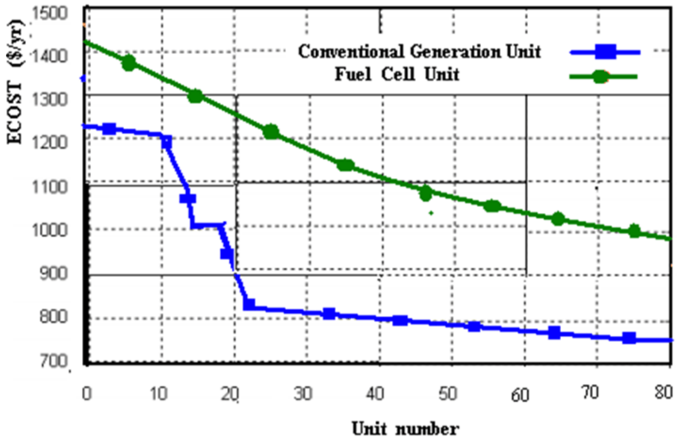

Fig. 8: Ecost Variations when PVs or Conventional Generation Unit Varies.

8. Conclusion:

This paper showed that the effects of FCs on the reliability of the network had a different affect in compare with conventional generation unit. The reliability of the network changed when output production of FCs varied. This feature of FCs is the main factor for reducing the reliability of the network in comparison with the conventional generation units, although adding FCs to the network increases the reliability of the entire network. Because of output power of FC don't depend on climate status, so FC respect to other DGs such as photovoltaic arrays or wind turbines can increase more reliability of the system.

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