Voltage Sag Improvement in Distribution Systems in Presence of Dispersed Generation Resources

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***Abstract*—By the shift of power systems from their traditional structure towards the restructured system and willingness of the villagers for receiving energy in their houses have now resulted in a focus on "micro grid" units. Micro grid is called to small distributive generation units installed in the strategic points of the system near to load centers. These gridsinclude the gas turbine, micro turbine, fuel cells, solar cells, etc. Micro grid can either independently supply particularcommon loads or assist common load supply in combination with other sources. Distributed generations distribute power in closed or open sites in the form of grid connected for load centers. These products have numerous advantages and disadvantages, such as peak shaving, grid support, imbalanced voltage, etc. Application of micro grids in the power system architecture for economized generation and use of power is a widely growing issue. On one hand, the distribution companies are obliged to provide the energy with standard energy loss to their subscribers, which gives some motives to them towards loss reduction and use of micro grids. The American Institute of Electrical Engineering supplies the most reliable power with safety level of 99.9 %. However, this level is only suitable for lights and refrigerators and for some companies which have strategic computer systems a power supply with reliability level of 99.999999% is required; as using the power with reliability level of 99.9% they would have only 8751 hours of reliable power annually. In this regard, it seems that DISTRIBUTED GENERATIONs can significantly improve the reliability level, once being supported by the overall grid system [4]. The main objective of this paper is to investigate voltage sag and imbalance voltage of the micro grid when connected to the main power grid.**

Keywords—Power quality; voltage sag; distributed generation; fuzzy control; active power control

I. INTRODUCTION

By now, many definitions have been presented for the distributed generation (DG) systems. As a comprehensive definition, with no technological and generation capacity limitations, DG can be defined as energy supply source which is connected to either the distribution networks or customer [14]. Considering the different loads and load-hour profiles is a critical issue in DG supply planning. In the method proposed in this work, the hour profile of the grid loads are studied. Moreover, the penetration coefficient of DGs is an important parameter in energy loss reduction of the system. The cure of loss with penetration coefficient of DGs has a U form [11]. Different technologies such as fuel cells, generator diesels, solar cells, wind turbines, etc. can be utilized for power supply. The power supply sources can be fossil fuels, renewable energies, and storage resources with conventional generation capacity of several kilowatts to several ten megawatts. Among the advantages of DG sources, one can name decreased generation costs, loss drop, improved voltage fluctuation, improved power quality, simultaneous generation of thermal and electrical energies, harmonic reduction, improved generation efficiency, positive environmental impacts, etc. To obtain these advantages, it is required to determine the optimum place of source connection to the network and optimum voltage. Due to the pollutions induced by the fossil fuels and depletion of these fuels, a growing interest is developed in use of renewable energy sources [5]. Studying the importance of DGs in generation system shows that applying the island mode in the distribution system has permanent impacts on economic and technical problems. DGs should function in an optimum way in both grid connection and island modes, which can be met by adjusting the operational strategy. Technology of DG sources is developed in the form of island mode. In this paper, the operational strategy for DG sources was represented for both island and grid connected modes. This strategy consists of mean rate of frequency variations and real power transfer. Transfer of real power was conducted using the frequency adjustments. The results showthe proposed technique can boost efficiency in both island and network connected modes, while keeping the voltage and frequency in a reasonable range [10]. This paper also shows that island detector is necessary for protection of DG sources. The anti-island techniques of investors in DG sources were designed and tested at RLC loads. In this paper the basic anti-island technique, which is applied for synchronization of P-F and Q-V, is designed and tested under different island modes and the applied loads were tested on them. The static loads are frequency dependent at island mode. The developed anti-island technique in this work is designed for all critical states at static loads and constant RLC loads. The performance of the proposed method was tested to adjust load switching disturbances and voltage distortion. Unlike the methods proposed in the literature, the results of this work show that island tracing method is very suitable for frequency-dependent loads and system disturbances [1]. In the present work, an algorithm was proposed to determine the system capacitance to improve micro grid stability including coordination in DG sources. Here, the analysis sensitivity is controlled by rotor angle and initial speed of DG sources. For the cases of sudden error generation, the main determiner of the algorithm is the error generation point. The proposed method can be applied for a number of arbitrary DG sources and different error scenarios in both island and grid connected forms in the micro grid. The proposed algorithm satisfies initial stability of the fluctuation in DG sources. The algorithm also determines capacitance installation capacity and minimum time computation [3]. Selection of appropriate location and size of the DG sources is a basic multivariate function for renewable systems which have important impacts on safety and reliability of the power system. This study is indeed a development of previous works through gathering the problems of optimum size and localization in a realistic way on basis of power loss sensitivity and Kalman Filter algorithm. The proposed method was practically implemented in a 60 MW distribution grid in Seoul, South Korea, where the systematic optimum localization and effective status was developed using the power losses. Moreover, the applied Kalman Filter algorithm for determination of optimum load size works with the base load of 10 KW which is extremely smaller than the 10 MW mentioned in the previous studies, where this value is without the increased cost of computation. Such a 10 KW base is more realistic and suitable for practical tests systems [7]. This research was conducted on the base hybrid fuel cells of the DG systems to reduce voltage sag under balanced and imbalanced voltage conditions in power systems. In the system propose by their work, whenever a voltage sag occurs in the power system, the current control strategy serves based on fuzzy controller and active power management using the developed artificial neural network controller. This controller adds a high capacitance on based on the accessible power in the DC link. The results generally show suitable performance of the DG system [8]. In another work, the modified dynamic phase mode estimation method is proposed for relay protection in base frequency component with variable amplitude. In this research, the error flow is considered for a combination of DC offset removal and, while the components of base frequency and harmonics are eliminated with a constant amplitude. Here, the exponential function of DC offset is faded, the base frequency component is replaced with Taylor series, and then minimum square technique is applied to estimate error flow and stability time. Performance of this algorithm was evaluated in Simulink environment of MATLAB using the equations base and current error flow signal in wind turbine of Double-Fed Induction Generators. The results show that the proposed algorithm can accurately estimate the reduced amplitude and stability time in elements of base frequency [9]. In this paper, the problems of DG sources was assessed in a large scale for loss reduction in distribution grid using the improved analytical (IA) method. This method computes the optimum size for 4 different types of DG and computes an idea for determination of optimum location for DG sources. Also, a technique was proposed in this work to compute optimum power coefficient in qualified DG for electro-active power delivery. Furthermore, loss sensitivity factor (LSF) and exhaustive load flow (ELF) methods are presented in this work. IA was evaluated on 3 DG systems with different and complicated test sizes. The results revealed that IA method is more feasible as compared to LSF and ELF [6]. The modified dynamic mode phase estimation method was proposed in this research for relay protection in base frequency components with variable amplitude. The error flow was considered for the combined DC offset removal, while components of base frequency and harmonics with constant amplitude are removed. The exponential DC offset is removed and base frequency component is replaced with Taylor series, and then square minimum technique is applied for stability size and time. Performance of the algorithm was evaluated in Simulink environment of MATLAB using the base equations and error flow signal for DFIG wind turbine. The results show that the proposed algorithm can accurately estimate the reduced amplitude and stability time in the elements of base frequency [2].

II. THE CONTROLLER STRUCTURE OF THE DG SYSTEM

To develop and improve distribution system, there exists a high demand for DG installation from the customers and power suppliers. Many DG sources are connected to distribution grid by a nonlinear link such as voltage source invertor or current source invertor. The main purpose of parallel connection is to control the active power extended from DG. The performance of this link in reactive power control is similar to that of DSTATCOM. Reactive power control leads to voltage regulation in the point of common contact (PCC). The designed controlling system for this purpose is shown in Fig. 1. As shown in the figure, this controlling systems is composed of phase rectifier, reactive power, and active power controllers. Among the advantages of phase controller, one can name the fitting property, quick and soft response to the variations, and lack of sensitivity to variable changes which is among the requirements of distribution systems.

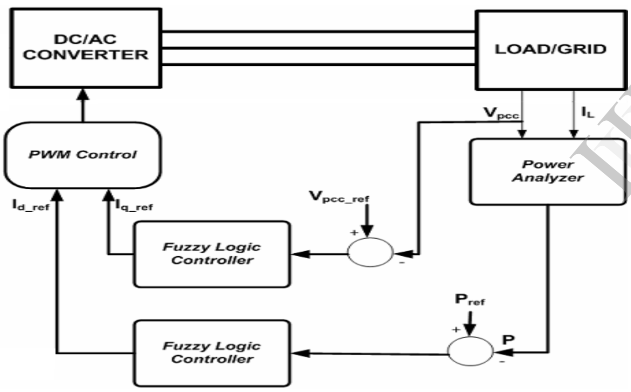

Fig. 1: Controlling structure of the DG system for voltage regulation and power control

Since the distribution system is intrinsically variable and its parameters rapidly change by addition of load to the cables, transformer saturation, and load dynamics, the controllers are required to be configured in a way that to have a low sensitivity to variation of parameters. This flexible structure of DG overcomes the slow response of load tap changing transformers (LTCT) applied for voltage regulation. Moreover, it replaces the linear compensators such as Thyristor Switched Capacitor (TSC) which is applied for reactive power compensation. In this paper, the fuzzy control was applied for voltage regulation and power control instead of the classic controllers such as PI. The advantage of fuzzy control over other systems is its capability of managing the nonlinear behaviors of the practical systems with complicated structure as it applies heuristic sciences and expert knowledge. The fuzzy controller has associative properties and is non-sensitive to parameter variations; besides, it needs no accurate mathematic modelling of the system.

A. Design of fuzzy controller for voltage regulation

The real inputs of the fuzzy Mamdani controller applied in this work are the scaled signals of effective voltage error (e_1) and error derivative (e_2). Seven triangular membership functions were chosen for each input and, ultimately, 49 "IF-Then" rules were developed for this system (Table 1). Each input signal of the fuzzy controller and output signal (e_1,e_2, Δiq_ref) is a fuzzy variable which is represented by seven linguistic variables: NB,NM,NS,Z,PS,PM,PM, and PB. The fuzzy rule database is designed in way that it is completely benefited from the relations between active and reactive power for delivering effective voltage quickly to its reference amount without any overshoot. Moreover the current-controlled PWM invertor can adjust iq current in an instant manner. For example, if e1 is large and negative and e2 is large and positive, Δ_{iq_ref} is small and positive. Based on this rule, when V_{ppc} is extremely smaller than V_{pcc_ref} and limits with high acceleration towards it, decisions are based on the slow growth of Δ_{iq_ref}. to prevent the overshoot of control signal, a termination condition is considered based on the following rule:If e1 is a medium and negative value and e2 is large and positive, Δ_{iq_ref} is large and negative. Therefore, in this state, current signal is rapidly dropped to prevent large overshoot of the effective voltage.

B. Design of fuzzy control for active power

This controller is for active power control which is carried out using the Mamdani fuzzy controller which makes decision based on the error between reference power and buss power of the distribution system and derivative of this error. Seven triangular membership functions were chosen for each input and, ultimately, 49 "IF-Then" rules were developed for this system (Table 2). Each input signal of the fuzzy controller and output signal (e1,e2, Δiq_ref) is a fuzzy variable. Here, Δ_{iq_ref} is a criterion of active power variations. The fuzzy variables are assigned by linguistic variables including positive large (PL), positive medium (PM), positive small (PS), zero (Z), negative small (NS), negative medium (NM), andnegative large (NL) which are expressed for error and error variations. In general, the controller must have quick and accurate response time. Typically, the quick response time results in an increase in overshoot of the control signal. However, the fuzzy controllers have relatively high response and low overshoot. For instance:

If e1 is NM and e2 is PL, Δ_{iq_ref} is PS. Once P_{bus} is remarkably smaller than P_{ref} and limits to it with high acceleration, it is decided that Δ_{iq_ref} is gradually increasing.

III. MODELLING OF DC/AC CONVERTER

The dynamic voltage source converter converts the regulated DC voltage from DC/DC converter to AC voltage for DG system through the pulse width modulation. Fig. 2 presents the circuit-based model of DC/DC converter. The differentiation equations of this converter are as follows:

$$\frac{di_k}{dt} = -\frac{R_s}{L_s} ik + \frac{1}{L_s}(V_{ik} - V_{sk}) \qquad (1)$$

Where, k = {a, b, c} is for the voltage signals and current of each phase; Rs and Ls are parameters of the first order filter model for elimination of harmonics introduced from the converter to the grid.

By applying dg to Eq. (1), the differentiation Eq. (2) is derived for dq field.

$$\frac{di_q}{dt} = \frac{-R_s\omega_s}{L_s} i_q - \frac{\omega s}{L_s} ksin(\delta + \theta s)V_{dc} - \frac{\omega s}{L_s}\sin(\theta)\, V_s \qquad (2)$$

Table 3show the parameters required for simulation of DC/AC converter model.

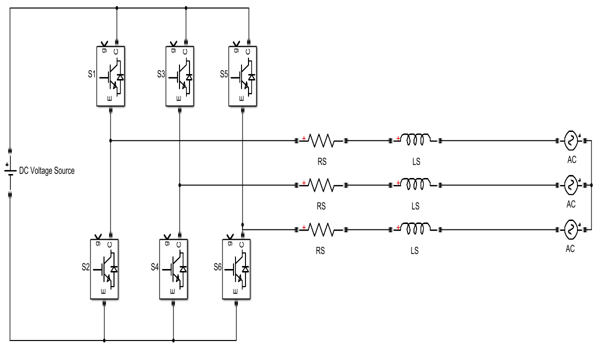

Fig. 2: Circuit based DC/AC converter model

Table 3: Parameters required for simulation of DC/AC converter model

R_s [Ω]	0.9
L_s [mH]	0.01
V_s [Volt]	220
f_s [Hz]	50

IV. SIMULATION RESULTS

To illustrate the strategic capability of the designed control against different disturbances in distribution system, the simulation results for voltage sage improvement are presented in this work. Fig. 3 presents structure of distribution system with DG source. As shown in the figure, the inverter is connected to the PCC Bus.

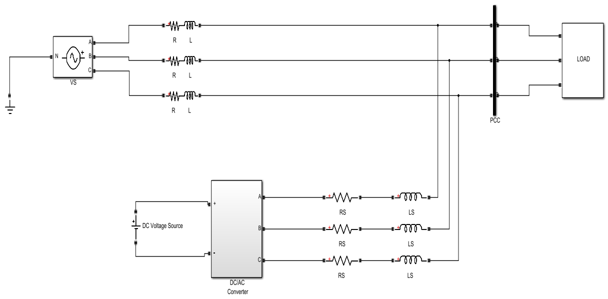

Fig. 3: Structure of distribution system with its attached DG source

Voltage sag has been recently noticed as an important problem in power quality drop. Fig. 4 illustrates a sample of symmetric voltage sag in distribution system. As shown in the figure, voltage sage of 40% occurs for the time intervals of 0.3 to 0.6 seconds.

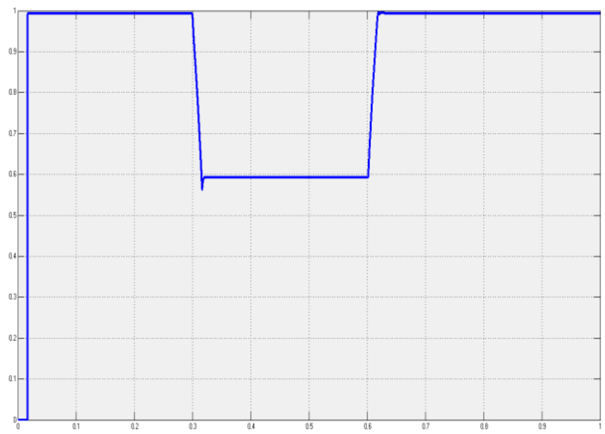

Fig. 4: Symmetric voltage sag in distribution system

Fig. 5 shows the effective voltage in PCC after applying control strategy. For times before 0.3 sec, PCC is adjusted to 1 per/unit. During the voltage sag the control strategy was able to maintain Vpcc up to an acceptable level and prevent frequent overshoots. Once the voltage sag is controlled, the effect Vpcc is still remained at 1 per/unit.

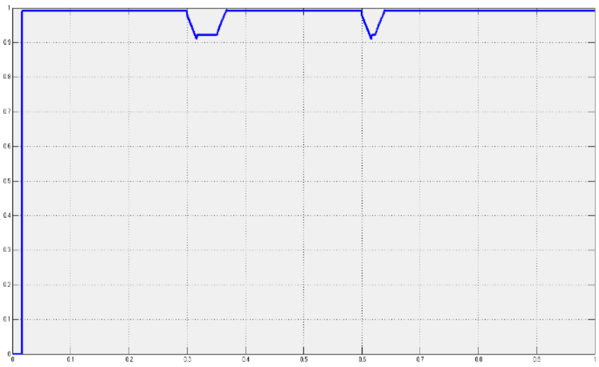

Fig. 5: Vpcc voltage for voltage sag times

Fig. 6 presents dynamic variations of load drop for voltage sag times. Also the active and reactive powers during the voltage sage are shown in Fig. 7. As shown in the figure, during the voltage sag in the distribution system, the voltage is gradually increased and the control strategy is able to prevent voltage overshoot and creation of transitional states in the output voltage.

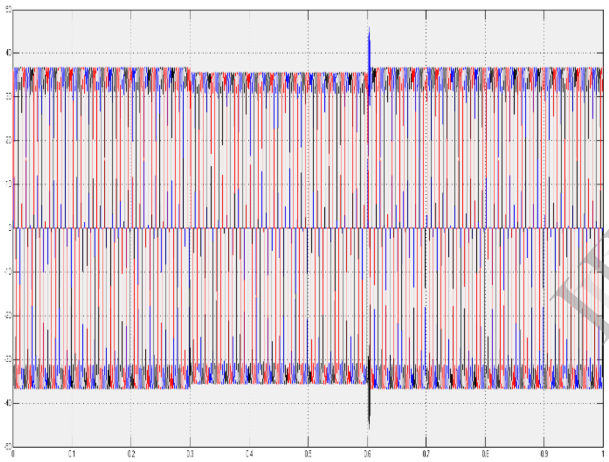

Fig. 6: Dynamic variations of nonlinear load at the voltage sagemoment

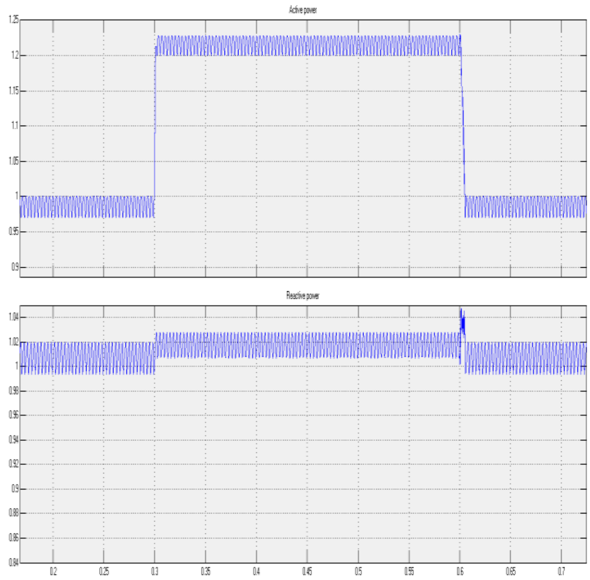

Fig. 7: Variations of active and reactive power at the voltage sage moment

V. CONCLUSION

In this work, the intelligent control strategy was proposed for connection of DG resources to the distribution system. The designed control circle consists of a fuzzy controller for control of active power from the DG source and improvement of power quality through the DC/AC converter. Among the advantages of this fuzzy controller are its associative properties, quick and soft response to variations, and lack of sensitivity to variation of parameters which is among the requirements of distribution systems. The simulation results indicates capability of the designed control strategy during the voltage sag in the distribution system.

Table 1: Fuzzy rules database for fuzzy controllers of the voltageregulation.

Δ_{iq_ref}		e_2						
		NB	NM	NS	Z	PS	PM	PB
e_1	NB	PB	PB	PB	PM	PM	PM	PS
	NM	PB	PB	PM	PM	PM	Z	NB
	NS	PB	PM	PM	PM	PS	NS	NB
	Z	PB	PM	PS	Z	NS	NM	NB
	PS	PB	PS	NS	NM	NM	NM	NB
	PM	PB	Z	NM	NM	NM	NB	NB
	PB	NS	NM	NM	NM	NB	NB	NB

Table 2: Fuzzy rules database for fuzzy controllers of active power.

Δ_{id_ref}		Rate of change of error						
		NL	NM	NS	Z	PS	PM	PL
Error	NL	NL	NL	NL	NL	NM	NS	Z
	NM	NL	NL	NL	NM	NS	Z	PS
	NS	NL	NM	NS	NS	Z	PS	PM
	Z	NL	NM	NS	Z	PS	PM	PL
	PS	NM	NS	Z	PS	PM	PM	PL
	PM	NS	Z	PS	PM	PL	PL	PL
	PL	Z	PS	PM	PL	PL	PL	PL

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