The Control Technique For Integration Of DG Units To The Electrical Networks

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Abstract: This paper proposes with a control method for unification of distributed generation resources using fuzzy logic controller to the utility grid. The theme is to reduce total harmonic distortion reduction using fuzzy logic controller in utility grid while delivering to nonlinear loads. The proposed method provides compensation for active power reactive power and harmonic load current during connection of distributed generation resources to the utility grid. Matlab Simulink model of the system is done using fuzzy logic controller.

Keywords: DG; RDS; Power Quality;

INTRODUCTION

An Electric power system comprises of a generating system, a transmission system and a distribution system. Generating station convert fuel energy into electricity, transmission system connects the generating stations and distribution substations and distribution system distribute power to consumers. In view of network structure, transmission and distribution systems are different. Generally, transmission system will have loop structure and distribution system tends to have a radial structure.

Distribution Systems:

Distribution systems are employed with radial structure in order to obtain operational simplicity. By means of an interconnected transmission network, primary distribution substation receives power from generating stations. Radial Distribution System (RDS) network is passive in nature and transfers power to consumers from the substation. Thus, in RDS the power flow is unidirectional. In case of distribution lines, due to high R/X ratio, high voltage drops, large power loss will occur. Everyday distribution networks are experiencing many changes in the load. At most of the nodes, RDS experience a sudden collapse in the voltage during critical load conditions because of low voltage stability index. In this thesis, for RDS a voltage stability index (VSI) is proposed for all the nodes. It is observed that node with minimum VSI value is more sensitive and leads to collapse in voltage. During past years, several techniques were implemented by placing dispersed sources injecting reactive power like capacitor banks in order to obtain improvement in voltage and to reduction in power losses. Even through the implementation of capacitor placing method which is promising in nature, the voltage profile improvement obtained is below desired voltage level (1.0 p.u.). As RDS is passive in nature, it is less reliable.

Many solutions are suggested recently by incorporating electrical sources based on renewable energy technology to overcome the passiveness of RDS and also to improve reliability of the system and voltage profile. These embedded generations in RDS are called as Distributed or Dispersed Generation (DG).

Distributed Generation (DG):

In recent years, alternate solutions to traditional power stations have been given a high priority due to the limited presence of fuel resources and also to meet electric energy demands. Thus, the renewable resources of energy are considered as the alternative solution to existing fuels. When compared with large fossil fuel based power plants, the sizes of renewable energy based generators are small. They are well suited for low voltage RDS. Originally power systems are designed based on power flow in single direction, but the DG concept has led to new considerations concerning the distribution networks. The penetration of Dispersed Generation impacts the distribution system operation in a beneficial way or it may increase line losses which is a negative effect. Positive aspects of DG are: provides Voltage Support, reduces Power Loss, and the negative aspects of DG are Dynamic Stability and Protection Coordination. So, for adopting the DG into distribution network, care should be taken for technical constraints and penetration levels, in such a way that the benefits should be maximised. Dispersed generation is a power source directly connected to customer site or to distribution network. It consists of two aspects:

1. DG located on customer side or directly to distribution system
2. Demand-side resources, such as load management systems and energy efficiency options.
Interesting aspect of DG resources is, it acts as a means for customer demand and also generate the power on the customer side. Now-a-days distributed capacity includes all impacts of DG and distributed resources and reserve capacity for minimizing requirements for over dimensioning of distribution/ transmission system. Many approaches are proposed for placing and sizing of Dispersed Generators. An easy technique for reducing the real power loss, improving the voltage profile is presented. Power flow analysis is done by using forward-backward sweep technique. In RDS, the optimal locations for placing the DG units are identified by VSI technique. The optimal sizing of the DG units is computed by using Particle Swarm Optimisation (PSO).

A discussion about different controllers in DG system and their ability to compensate low-order harmonic components presented in the utility grid was given. Finally, an overview of grid synchronization strategies, their influences, and roles in the control of DG system on normal and faulty grid conditions were discussed, a control concept was proposed that provides sharing of harmonic load currents between parallel connected converters without mutual communication. In this project, a converter operates as an active inductor at a certain frequency to absorb the harmonic current components. However, the exact calculation of grid inductance in real-time systems is not simple, and it can deteriorate the performance of the proposed control strategy. The fact that power grids are faced with unexpected and unavoidable disturbances and uncertainties complicates the design of a practical plug-and-play converter-based DG interface. A robust interfacing scheme for DG converters featuring robust mitigation of converter grid resonance at parameter variation, grid-induced distortion, and current-control parametric instabilities is presented in [1,6].

To ensure high disturbance rejection of grid distortion, converter resonance at parameter variation, and parametric instabilities, an adaptive internal model for the capacitor voltage and grid side current dynamics is included within the current-feedback structure.

In [1,7], a control algorithm of three-phase voltage source converter (VSC) has been proposed for integration of renewable energy resources to the main grid through an output L-type or LCL-type filter. The proposed controller provides active damping of the LCL resonance mode, robustness with respect to grid frequency, and impedance uncertainty. A control technique is proposed into determine which power lines should be inserted during the presence of DG. In, an algorithm is suggested in order to design feasible line drop compensation parameters. This algorithm guarantees the satisfaction of voltage constraints for all possible variations in DG output. In, DG unit was modeled as a PV node, and its control was coordinated with existing volt/var controls to minimize distribution losses.

In all the proposed methods, a solution has been proposed for an important problem in electrical networks. In this paper, the authors propose a design of a multipurpose control strategy for VSC used in DG system. The idea is to integrate the DG resources to the power grid. With the proposed approach, the proposed VSC controls the injected active power flow from the DG source to the grid and also performs the compensation of reactive power and the nonlinear load current harmonics, keeping the grid current almost sinusoidal during connection of extra loads to the grid. The exact feedback linearization theory is applied in the design of the proposed controller. This control technique allows the decoupling of the currents and enhances their tracking of the fast change in the active and reactive power.

**ALLOCATION OF DG IN DISTRIBUTION NETWORKS**

**Introduction**

Loss Minimization in power networks has assumed greater significance, in light of the fact that enormous amount of generated power is continuously squandered as losses. Studies have demonstrated that 70% of the aggregate networks losses are happening in the distribution networks, while transmission lines represent just 30% of the aggregate losses [1]. The pressure of enhancing the overall proficiency of power delivery has forced the power utilities to reduce the loss, particularly at the distribution level. The following approaches are embraced for reduction of distribution networks losses [1-2]:

- Reinforcement of the feeders.
- Reactive power compensation.
- High voltage distribution networks.
- Grading of conductor.
- Feeder reconfiguration.
- Distributed Generator placement.

Smart grid concept is expected to become a backbone in Europe future electricity network [10].

In achieving a Smart Grid concept, a large number of distributed generators (DG) are needed inside distribution network which is prognosed to supply up to 40% of the distribution network’s load demand. This substantial number of DG is obliged to take part in enhancing the security, reliability and quality of electricity supply by providing active
power and other subordinate services such as regulating the voltage by providing their reactive supply to the network. One of the characteristics of future electricity network under smart grid idea is to have an efficient transmission and distribution network that will reduce line losses [3-9]. Minimizing losses inside power transport networks will bring about easier utilization of fossil fuel consequently reduced emanation of air pollutant and greenhouse gasses. Coordinating of 

DG inside distribution network reduces power losses in light of the fact that some share of the required load current from upstream is generously reduce which result lower losses through line resistance. Further reduction of losses can be attained by intelligently managing reactivepower from introduced DG [10].

Distribution Network Power Losses

An active power loss in the line depends on magnitude of the current flows through the line and resistance of the line. In ac distribution circuit, due to electric and magnetic field produce by the flow of time varying current, inductance and capacitance might be noteworthy. At the point when current flow through these two components, reactive power which transmit no energy is produced. Reactive current flow in the line adds to extra power losses in addition to active power losses mention previously. Integration of DG already reduced active power losses because some portion of power from upstream is already reduced. Losses reduction can be further reduced by controlling the voltage profiles in the network. In conventional practice, capacitor banks are added in the distribution network to control the flow of this reactive power.

These capacitor banks can be switched in and out using voltage regulating relay to deliver reactive power in steps but it lowered power quality delivered to the customer as it leads to step changes in node-bar voltage.

\[ P_{loss}(x) = \sum_l 3 i_l^2 R_i \quad \forall i = N_l \]

Distributed Generation

Operational and Planning Issues with DGs

Distributed Generators (DG) are crisply characterized as “electric power sources joined specifically to the distribution system or on the client side of the meter” [3]. This definition for the most part obliges a variety of technologies and execution crosswise over diverse utility structures, while evading the pitfalls of utilizing more stringent criteria focused aroundstandards, for example, power ratings and power delivery area. Distribution planning includes the investigation of future power delivery needs and options, with an objective of creating a precise course of action of increases to the networks required to attain agreeable levels of service at a minimum overall cost [4]. Executing DGs in the distribution system has numerous profits, yet in the meantime it confronts numerous restrictions and limitations. DG units, being adaptable, could be built to meet immediate needs and later be scaled upwards in capacity to take care of future demand growth. Versatility permits DG units to reduce their capital and operations costs and therefore substantial capital is not tied up in investments or in their support infrastructure. Investment funds can likewise be accomplished since infrastructure updates, (for example, feeder capacity extensions) might be deferred or altogether eliminated.

From a client perspective, funds may be gathered from the extra decision and flexibility that DGs permit with respect to energy purchases [3-6]. On the other hand, then again, installing DG in the distribution networks can also increase the complexity of networks planning. DG must be satisfactorily introduced and facilitated with the existing protective devices and schemes. Higher penetration levels of DG may cause conventional power flows to alter (reverse direction), since with generation from DG units, power may be injected at any point on the feeder. New planning systems must guarantee that feeders can suit changes in load configuration. These limitations and problems must be settled before picking DG as a planning alternative. Some of the associated issues in distribution networks with penetration of DG units are as discussed next.

DG AND POWER QUALITY

The Concept of Power Quality

The definition of power quality given in the IEEE dictionary originates in IEEE Std 1100 [21]: Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment. Despite this definition the term power quality is clearly used in a more generic way.

Within the industry, alternate definitions or interpretations of power quality have been used, reflecting different points of view. Therefore, this definition might not be exclusive, pending development of a broader consensus. A point of view of an equipment designer or manufacturer might be that power quality is a perfect sinusoidal wave, with no variations in the voltage, and no noise present on the grounding system. A point of view of an electrical utility engineer might be that power quality is simply voltage availability or outage minutes. Finally, a point of view of an end-user is that power quality or “quality power” is
simply the power that works for whatever equipment the end-user is applying.

While each hypothetical point of view has a clear difference, it is clear that none is properly focused. An environment where the equipment designer or manufacturer clearly states the equipment needs, and the electrical utility engineer indicates the system delivery characteristics, and the end-user then predicts and understands the equipment operational disturbances that will likely be encountered on a yearly basis is a better scenario. This allows a cost justification to be performed by the end-user to either improve equipment operation by installing additional components or improve the electrical supply system through installation of additional, or alteration of existing components. [21]

Overview of Power Quality Phenomena

Overvoltage

When used to describe a specific type of long duration variation, refers to a measured voltage having a value greater than the nominal voltage for a period of time greater than 1 min. Typical values are 1.1 to 1.2 p.u. [22]. Overvoltages can be the result of load switching (e.g., switching off a large load), or variations in the reactive compensation on the system (e.g., switching on a capacitor bank). Poor system voltage regulation capabilities or controls result in overvoltages. Incorrect tap settings on transformers can also result in system overvoltages. Figure 4-1 shows a typical overvoltage waveform.

![Figure 4.1. Typical overvoltage waveform](image)

Undervoltage

A measured voltage having a value less than the nominal voltage for a period of time greater than 1 min when used to describe a specific type of long duration variation. Typical values are 0.8 - 0.9 p.u.

Undervoltages are the result of the events which are the reverse of the events that cause overvoltages. A load switching on or a capacitor bank switching off can cause an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances. Overloaded circuits can result in undervoltages also.

Sag

A sag is a decrease to between 0.1 and 0.9 p.u. in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min. Typical values are 0.1 to 0.9 p.u. [22]. To give a numerical value to sag, the recommended usage is “a sag to 20%,” which means that the line voltage is reduced down to 20% of the normal value, not reduced by 20%. Using the preposition “of” (as in “a sag of 20%,” or implied by “a 20% sag”) is deprecated. A sag is a decrease in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute. Typical values are between 0.1 p.u and 0.9 p.u.

PROPOSED METHODOLOGY

Proposed DG Model

Fig. 5.1 shows the schematic diagram of the proposed system. Conventional signs of voltages and currents components are also indicated in this schema, where \( R_c \) and \( L_c \) represent the equivalent resistance and inductance of the ac filter, coupling transformer, and connection cables; \( R_s \) and \( L_s \) represent the grid resistance and inductance up to the point of common coupling (PCC), respectively; \( v_k \) \((k=1,2,3)\) is the supply voltage components at the PCC; \( v_{sk} \) is the grid voltage components; \( v_{dc} \) is the dc-link voltage; and \( i_{sk}, i_{lk}, \) and \( i_{ck} \) are grid, load, and DG current components, respectively. In addition, the DG resources and additional components are represented as a dc current source which is connected to the dc side of the converter.

![Fig. 5.1. Schematic diagram of the proposed DG system.](image)

Voltage And Current Components in the Special Reference Frames

The proposed control technique in this paper is based on the analysis of voltage and current vector components in the special reference frames, e.g., 123(abc) to \( \alpha \beta \) and \( \alpha \beta \) to \( dq \) transformation. The Clarke transformation maps the three-phase instantaneous voltages and currents in the 123 phases into the instantaneous voltages and currents on the \( \alpha \beta \)-axes. In the next step, the \( \alpha \beta \) reference frame is transformed to the rotating synchronous reference frame, i.e., in \( dq \)-components. The synchronous reference frame uses a reference frame transformation module, to transform the grid current and voltage waveforms into a reference frame that rotates synchronously with the grid.
voltage. By means of this, the control variables become dc values; thus, filtering and controlling can be achieved easily [29].

Fig. 5.2. Voltage and current components in special reference frames.

Fig. 5.2 shows the voltage and current components in $\alpha\beta$ and $dq$ reference frames. Considering $d$-axis vector in the direction of voltage vector in this transformation, the $q$-component of voltage in rotating synchronous reference frame is always zero ($v_q = 0$) [30]. Therefore, the instantaneous angle of grid voltage can be calculated as

$$\theta = \tan^{-1} \frac{v_\beta}{v_\alpha},$$

(1)

In other words, if we consider the instantaneous angle of load voltage by (1), the reference voltage vector will be in the direction of $d$-axis vector of load voltage, and $q$-axis vector of load voltage will be zero. According to Fig. 5.2, the magnitude of the voltage at the PCC can be calculated as

$$v_{ref} = |v_\alpha^2| = |v_\beta^2| = |v_{\alpha\beta}^2| = \sqrt{v_\alpha^2 + v_\beta^2},$$

(2)

RESULTS AND DISCUSSION

In order to demonstrate the high performance of the proposed control technique, the complete system model was simulated using the “Power System Blockset” simulator operating under the Matlab/Simulink environment. The schematic diagram and principle of the proposed model and the control technique in an ac grid are shown in Fig. 6. The test model contains a power converter with power rating of 20 kVA. The maximum available value of DG source active power is 8 kW, which is also the active power reference included in the simulations. At first, capabilities of DG resources and flexibility of proposed control strategy to control the proposed VSC in providing active, reactive, and harmonic current components of different loads are shown, and the capabilities of proposed control method on reactive power tracking with constant output active power are considered. In addition, the simulated results have been used to analyze the total harmonic distortion (THD) of the utility grid current amid severe varying load conditions. During the simulation process, constant dc voltage sources have been considered as a DG source. In addition, the active power which is delivered from the DG link to the ac grid is considered to be constant. This assumption makes it possible to evaluate the capability of the proposed control strategy to track the fast change in the active and reactive power, independent of each other. For this purpose, when one of them is changed, another one must be constant. To simulate a real ac grid, the load is connected and disconnected to the power grid randomly, and grid current waveform will be compared with each other under various loads and conditions.

Fig. 6 Load voltage, load, grid, and DG currents before and after connection of DG and before and after connection and disconnection of additional load into the grid.

Fig. 7(a) shows that, after connection of additional load to the power grid at $t = 0.2$ s, converter injects the maximum active and reactive power by connection of DG source to the grid. However, in this case, the maximum power of proposed converter is less than the power which is needed to supply the grid-connected loads. Therefore, the remaining power is injected by the utility grid. As shown in this figure, the utility grid injects high-quality current waveforms even under the connection of nonlinear loads to the grid, and load harmonic currents are provided by DG. There are some sharp edges on current waveforms which are related to high-order harmonic frequencies and created during switching of thyristor converters. In addition, the production in control circuit of DG system is delayed for around one cycle. This is due to the settling time of proposed MPHPF filter, in DG’s control loop. Fig. 8(b) shows that, with the same delay as before, additional load is removed at $t = 0.35$ s. As shown in this figure, after the pass of the transient times, the injected current from grid to the load becomes zero, and DG link supplies all the required power to supply the proposed nonlinear load.
Fig. 7. Grid, load, DG currents, and load voltage (a) before and after connection of additional load and (b) before and after disconnection of additional load.

Fig. 8 shows that, after the transient times during connection of additional load to the main grid, the load voltage and grid current are in phase, and the grid does not need to provide reactive and harmonic currents for the load which is shown for three phases.

Fig. 8. Phase-to-neutral voltage and grid current for phase

The ability of control loop to track the reference current trajectories of \(d\)- and \(q\)-axes, during connection of DG link to the grid and, also, connection of additional load to the grid, is shown in Fig. 9. Fig. 9(a) shows that, before connection of additional load to the grid, the actual \(d\)- and \(q\)-axis current components of DG’s control loop track their reference trajectory precisely. However, according to Fig. 9(b), after connection of additional load to the grid, the actual \(d\)-axis current component of DG tracks half of its reference trajectory which is equal to its maximum active power (reference active power), and all the reference trajectories of reactive current change.

Fig. 9. Reference currents track the load current (a) after interconnection of DG resources and (b) after additional load increment.

CONCLUSION

A multi-objective control algorithm for the grid-connected converter-based DG interface has been proposed and presented in this project. Flexibility of the proposed DG in both steady-state and transient operations has been verified through simulation and experimental results. Due to sensitivity of phase-locked loop to noises and distortion, its elimination can bring benefits for robust control against distortions in DG applications. Also, the problems due to synchronization between DG and grid do not exist, and DG link can be connected to the power grid without any current overshoot. One other advantage of proposed control method is its fast dynamic response in tracking reactive power variations; the control loops of active and reactive power are considered independent. By the use of the proposed control method, DG system is introduced as a new alternative for distributed static compensator in distribution network. The results illustrate that, in all conditions, the load voltage and source current are in phase and so, by improvement of power factor at PCC, DG systems can act as power factor corrector devices. The results indicate that proposed DG system can provide required harmonic load currents in all situations. Thus, by reducing THD of source current, it can act as an active filter. The proposed control technique can be used for different types of DG resources as power quality improvement devices in a customer power distribution network.

REFERENCES


AUTHOR’s PROFILE

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