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Research paper

Transient Behaviour of a Microgrid and Its Impact on Stability during Pre and Post Islanding -A Novel Survey

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Abstract

Over the last 2 decades, significant advancement has been made in microgrid. The stability on microgrid will talk about issues relating to intentional and unintentional islanding conditions. Having observed the recent literature, the growth of inverter interfaced Distributed Generation with microgrid cases a pressing issue in stability. To symbolise the significance of stability, this article carries out an extensive review about the problems in transient stability and detailing the steps taken by various authors that lead to the system stable. To date there are lots of work in analyzing system stability in microgrid. From which this article focuses about the various stability issues and maintaining it different control techniques are reviewed

Keywords: *Microgrid, Distributed Generation, Transient Stability, Droop control, Storage devices.*

1. Introduction

Microgrid have brought a drastic revolutionary change in the existing power sector by its peculiar plug and play feature, which makes its operation possible even in worse geographical landscape and thereby maintaining a reliable power supply to load centres [1]. These microgrid are equipped in a low/medium voltage profile, incorporating Distributed Generation (DG), controllable loads and controlling circuits. The DGs are small scale power generation technologies and can be positioned in a site adjacent to the load centre [2]. In accordance with the output obtained from the DGs, the microgrid is classified into AC and DC microgrid.

In current scenario, DGs anchored within the microgrid predominantly makes use of Renewable Energy Sources(RES) such as photovoltaics, wind energy, ocean energy etc., It is important to note however, that most of DG with renewable energy provides DC supply. So, for the sake of converting it, the DC microgrid are interfaced to Voltage Source Inverter (VSI) and AC output is extracted to deliver power to load centres.

The microgrid fashions on two modes, namely grid-tied and island mode [3]. The microgrid are connected to the main grid through a Point of Common Coupling (PCC) in the former mode and works separately (without the help from main grid) in an independent aspect in the later mode [4].

A typical microgrid layout is represented in the Fig.1 below:

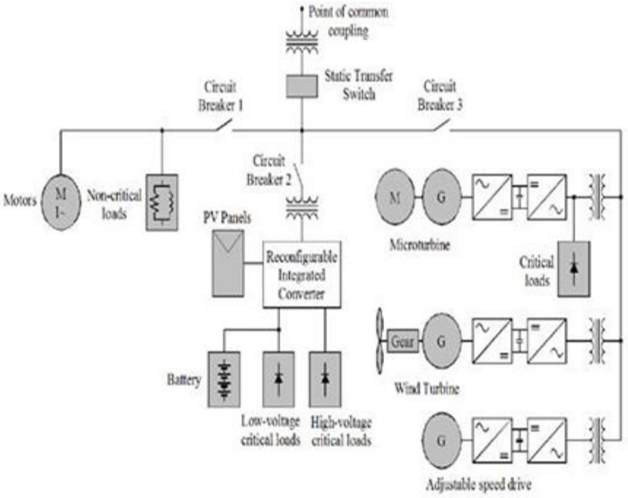

Fig. 1: Microgrid Layout

1.1 Technical Challenges in Microgrid

Microgrid are more prone to loss of stability owing to its low inertia. During its operation in grid connected mode, the main phenomenon to be considered is the term called “grid synchronization”. This synchronization is done by satisfying the standard interconnection requirements as listed in [5], [6] to maintain the stability and reliability of the system from customer point of view.

When these standards are not adopted, problems related to imbalance in load, improper load sharing, transient instability etc., are created. When the microgrid switches to another mode i.e.

islanded mode, many peculiar problems related to stability and power quality emanate as detailed in [7] and [8]. To alleviate thess issues, control strategies are utilized in this mode, which in turn again complicates the control of microgrid [9]. Also the task of maintaining the voltage, frequency, power factor, stability etc., should be taken care by the microgrid itself without getting support from the main grid. Accordingly many control strategies such as PQ droop control, Master slave control, P-f control, Q-V control are used in [10],[11] to mitigate the risk of complete system blackout while islanding. Another distinctive problem is the penetration of RES, into the microgrid, as their outputs are uncontrollable due to the unpredictable weather changes [12]. Controller analyses for non-linear system[33-42]. Hence there occurs a need to maintain the stability of the system to provide a seamless power flow to the load centres. This article has surveyed some of the technical problems occurring in the microgrid and remedial actions have been taken to overcome it.

The overall organization of the paper is framed as follows: Section II deals with the stability if the microgrid in island operation, Section III surveys about the droop control techniques which help in stability enhancement, Section IV enlists some storage devices that maintain stability and Section V describes some special cases based on hybrid microgrid systems.

2. Stability Issues in Islanded Mode of Operation

Microgrid requires serious attention under the case of islanding in order to prevent it from the occurrence of loss of stability. Several faults have been considered and different methods have been put forth in [13], [14], [15], [16], [17] and [18] to maintain the stability in island mode are enlisted below:

In [13], the different conditions considered are pre-planned islanding, load shedding, generator loss and failure in disconnecting unforeseen loads. Under all the cases, the frequency of the MG drops down and there occurs a threat to stability. For the sake of maintaining it, Proportional-Integral (PI) gain constants are adjusted in the speed and voltage regulator which in turn damps the frequency oscillations in a short duration. In addition to this, for the sake of maintaining stability, large loads which are connected in the grid are shed in [14] and no overloading condition is considered.

The scheme by which the loads are shed with frequency as an operating parameter is explained elaborately in [15]. Here an Under Frequency Load Shedding (UFLS) scheme, which is irrespective of the microgrid network parameter (in particular the inertia constant), is adopted. Shedding the load generally affects the generation; also variations in system parameters are experienced. This method does care about the power variations and sheds the load in accordance with it, providing effective results even under power deficit and voltage sags.

The stability of the microgrid is also affected by the type of load connected to it and the responsiveness of control strategy used for DG interface. Article [16] investigates the effect of different types of control strategy of the inverter-interfaced DG over MG stability subsequent to faults. The model considered here consists of synchronous and inverter based DG along with non-linear loads (say induction motor).

The control strategies adopted are Master/Slave control, Droop based control, P&Q control and current injection control strategy. The performance of different control strategies over different fault reveals the following results:

1) Current injection control provides faster and smoother transient response than the PQ Droop control strategy.

2) Droop control contributes more to the system stability when compared to Master/Slave control.

A recent study which adopts an intelligent detection, load shedding and reclosure algorithm was conferred by the authors of [18], to maintain the stability as said before. The MG is intentionally islanded from the main grid by detection algorithm, when the voltage and frequency limits are being violated in the main grid. And later when the MG is in island mode, it should be capable of maintaining its voltage profile and frequency as constant. In case, if the load demand is high, the loads are shed on the basis of load shedding algorithm. Another algorithm is also proposed in this article namely, reclosure algorithm, which helps to resynchronise the MG with the main grid by shifting the mode of operation of the controller to the grid tied mode.

Some peculiar cases experienced in [17] are also considered into account, such as two parallel connected inverters supplying power to the loads and not providing sufficient damping characteristics.

The authors put forth a novel adaptive transient droop control strategy to ensure the transient stability and maintaining proper power sharing between the DERs at steady state in addition to maintain active and reactive power sharing between the DERs at transient state.

At the time of power sharing, different modes of oscillation are affected and low frequency noises appear in the output. To minimise all these effects and to satisfy the objective, the conventional droop control of the inverters are modified a little i.e. active and reactive power derivative terms are added to the conventional droop controllers as transient droop gains.

These transient droop gains improve the transient performance and damp the low frequency oscillations along with damping of oscillatory modes and thereby providing proper power sharing between the DER's.

3. Enhancement of system stability by using droop control techniques

When the MG is in grid tied mode, the MG must synchronize its parameters with the main grid parameters to avoid stability problems. The control of the whole MG structure gets complicated when the MG switches to island mode. This complexity arises due to control of all the electrical parameters by the MG alone. In addition, stability problem arises in transition mode too. So to mitigate these complexities, many kinds of droop control techniques have been developed. Some of them [19], [20], [21], [22], [23] and [24] are discussed in this section:

The authors of [20] have put forth a new control strategy to enhance the power quality (in particular V-f regulation and power sharing) of the grid in autonomous mode. In addition with the effect of power quality issues, problems caused by non-linear loads are also considered. This control strategy comprises of conventional PI (Proportional-Integral) regulator and two control loops as mentioned below:

1) Inner current control loop
2) Outer power control loop

The structure of the microgrid consists of an inverter based DG operating in autonomous mode supplying non-linear load (say induction motor). The proposed power loop controller provides best response when the microgrid transists from grid-tied to isolated mode. The proposed current loop controller warranties perfect follow up of transients and retains the rated voltage. The result shows that the proposed method delivers excellent voltage and frequency response during islanding mode even with non-linear loads and also performs good in power sharing.

Article [23] discusses about two sorts of droop control technique, which is used in grid tied and island mode. When MG is in grid-tied mode, PQ control strategy is applied in the interface inverter, which acts as a controlled current source to maintain the stability. But this control strategy does not provide better result in autonomous mode because the voltage and frequency ratings must be maintained by the interface inverters in addition with maintaining the stability. So a separate control strategy called V/F control strategy is applied during isolated mode, which acts as a controlled voltage source and the voltage- frequency ratings are maintained within the MG without the help of main grid. Thus a separate type of control strategy is applied for each modes of operation and the system stability is maintained.

Even though the previous method maintains the stability, it suffers from serious disadvantage when shifting from one mode to another, because transient spikes arise during transition. To solve this problem, dual mode droop converters with well designed power loop are employed in [21]. This control strategy works in both operating mode and smooth transferring is achieved. Thus voltage fluctuations and transient spikes of AC bus are minimised. Secondly smooth transition is achieved in this article. Smooth transition refers that the voltage, frequency, amplitude of the MG should not vary suddenly during transition. A new proposed pre-synchronisation control with Software Phase Locked Loop (SPLL) principle helps the MG to achieve a smooth seamless transition.

The impact of P-f, Q-V and P-Q droop control during transient stability on a microgrid are discussed by the authors of [22], at the time of islanding (due to fault) and start of a motor load. The P-f and Q-V control are adopted in inverter interfaced DER and PQ control is adopted in an asynchronous generator. It is observed by the result that, at the time of start of a motor, it absorbs more amount of active power which in turn leads to frequency drop. This drop is compensated by sharing of active power among the microsources (adopted with P-f and Q-V control) and supplying the required active power to the motor load. The PQ control mitigates the change in frequency under transient. During island mode, the voltage and frequency collapses due to increased absorption of reactive power. The result shows that, due to prolonged consumption of reactive power, the total voltage collapses in the system.

The authors of [24] have explored the performance of master-slave control and voltage droop control strategies over a DC microgrid. From the simulation results, it is revealed that voltage droop control method improves the system stability and reliability comparatively.

A comparison of transient performance over a 3 phase to ground fault occurring in the utility grid side is analysed in [19] with different combinations of DERs such as,

(a) Synchronous Generator (SG) alone.
(b) Inverter with droop control strategy.
(c) SG with PQ Inv-DG.
(d) SG with Droop Inv-DG.

Also the Circuit Switching Time (CST) for each combination is calculated. The greater the CST, the system is said to be more transiently stable towards the fault. In all the cases when fault occurs, the MG is switched to island mode at once. At the time of fault, the terminal voltage of the SG drops rigorously and the rotor speed accelerates much fast so that the MG can even go to unstable state. In order to avoid it, the CST for each combination is analysed.

In case (a), after the MG is islanded, the SG takes up the load and recovers a new steady state value. The rotor speed deviations are also maintained within a limited value due to speed governor response. The simulation results of CST obtained is comparatively lesser than that obtained in case (d).In case (b), DERs with droop control strategy is considered. When the MG is switched to island mode, the voltage and frequency settle to the pre-fault condition rapidly due to fast control technology. This shows that Droop Inverter DG provides good voltage and frequency characteristics than SG. But this statement is not practically possible as inverters do not permit large short-circuit current and require proper relay settings. In Case (c), the PQ Inverter DG does not provide any voltage support to the SG and risks the stability of the MG. When voltage drops due to fault, the PQ Inverter DG maintains its active power output by decreasing the active power demand of the SG which in turn speeds up the rotor. On the other hand, the reactive power decreases which in turn collapses the MG. The result is almost equal to zero which implies that this combination is not transiently stable. In case (d), the Droop Inverter DG supports a lot for maintaining the voltage along with the SG. Here different proportions of SG and Droop Inverter DG outputs are said to deliver demand. The CST obtained in this case is high until the SG takes 75% of the rated capacity. Once 75% of rated capacity is taken, the CST starts to decrease. This shows that this combination is transiently stable under fault condition.

4. Maintaining the Stability by Employing Storage

This section emulates an overview of storage devices to maintain the stability of the MG in case of frequency and voltage profile fluctuations. The authors have employed different storage devices in [25], [26], [27] and [28] and the transient analysis is done.

In [25], the frequency fluctuations during islanded mode in MG are damped by using Superconducting Magnetic Energy Storage System(SMES). The SMES either releases (below rated value) or absorbs (above rated value) its energy at the instant of frequency fluctuations to maintain a constant value. In addition performance of SMES with single and double magnets is compared. The technical difference is that, the dual magnet SMES produces twice the output power as produced by single magnet SMES and provides better frequency stabilisation during frequency fluctuation although both SMES have same capacity.

In [26],the authors have discussed about two cases 1)comparison is carried between storage devises verses conventional Power System Stabiliser and governor model, 2) efficiency of thermal storage system over the batteries are examined. In case (1) the frequency oscillations are damped approximately in the same rate in both the storage device and PSS governor model, but there is an increase in voltage profile and transient oscillations are also damped soon when storage systems are employed. In case (2), the results reveal that, thermal storage systems have high absorption power and provide more output for same absorption rate as that of the batteries.

Taking into account only Wind Power Plant (WPP) in the MG, the authors of [27] have encountered few problems and explored a suitable storage system for maintaining the frequency stability. The WPP run under different operating conditions and the system's dynamic response is altered all the time. Also when number of WPP are erected in the MG, there arise frequency oscillations. To mitigate these problems, Battery Energy Storage Systems (BESS) are employed in the MG and the simulated results show that the frequency oscillations are damped out well, leading to perfect maintenance of frequency stability.

The fluctuating nature of the Renewable Energy Sources (RES) such as wind, thermal, photovoltaic's etc., in the MG jeopardises the system stability. Article [28] presents an advanced short term Distributed Energy Storage (DES) which supply the required active power thereby maintaining the voltage profile if the system. The DES considered here are Super Magnetic Energy Storage (SMES), Super Capacitors(SC) and Flywheels. They provide the required output to compensate the mismatch in active power, in the existing system. Proper controllers are ensured to all of the DES as stated in paper and quick supply of both real and reactive power is obtained. The simulation output performed in MATLAB/Simulink platform states that, the proposed advanced short term DES systems are effective over transient and dynamic stability.

5. Stability Analysis in Hybrid Micro Systems

This session specially deals with the stability issues in hybrid microgrid. Hybrid microgrid generally refers to combination of AC and DC microgrids or different combinations of Distributed Energy Resources (DER) or combination of DER with different control strategy etc., In all these cases the important thing to be maintained in the microgrid is the system stability. In the proceeding context different hybrid microgrid structures with different controls are discussed in [29], [30], [31] and [32].

The small signal stability of the multi machine power system (say IEEE-9 bus system is considered in this paper) is analysed, with and without the connection of a MG by D. Padma Subramanian et all in [31]. The microgrid structure consists of wind energy conversion system, PV array module and Marine current energy system. It is very clear from the results of eigen value analysis that, the stability of the system remains unaltered without MG interface and when the MG is connected to the system the small signal stability is affected.

Paper [29] discusses the transient behaviour of the MG in islanded mode which comprises of DFIG based wind turbine and a diesel generator. The heuristic nature of this hybrid system is that, MG results in insufficient supply of reactive power to the loads. This is because reactive power supplied by the SG is absorbed by the induction generator in addition to the loads. This causes a gap between supply and demand of reactive power. This reactive power compensation was done by using capacitor banks, FACTS devices with PI controller previously [z]. But capacitors fail to supply reactive power during wide load variation and selection of gain parameters in PI controllers was a tedious constrain. Asit Mohanty et al, authors have proposed a method to solve this problem using a combination of Adaptive Neuro-Fuzzy Inference System (ANFIS) based FACTS device with PI controller. UPFC acts as the FACTS controller. The gain constants of PI controller and the neural network parameters are optimised with the help of fuzzy inference system. This combination provides a better transient performance. Authors have performed a comparative study among MG without UPFC, with UPFC and UPFC with ANFIS system. A 2% increase in reactive power demand and change in wind supply is considered for each case. Results show that the later combination (UPFC with ANFIS system) provides better performance in terms of settling time, peak overshoot against all the load changes comparatively and provides better reactive power compensation with good transient performances.

Another performance analysis by Bhinal Mehta et al [30] on conventional generation and DFIG is deliberated here. The effect of DFIG based wind power generation over conventional power generation by synchronous generator is observed. Also the small signal stability with and without DFIG based wind turbine generator are compared. Here a two area system with four machines (say synchronous generator) is considered and the results of following cases with and without the presence of DFIG are explained:

Case: 1 Generator without AVR and PSS

Case: 2 Generators with AVR and PSS

Case: 3 One generator replaced by DFIG and other generators without AVR and PSS

Case: 4 One generator replaced by DFIG and other generators with AVR and PSS

Case: 5 Step wise wind power penetration by DFIG at a bus with other generators with AVR and PSS

In both the Cases 1 and 2 the system is said to be dynamically stable, but the incorporation of AVR and PSS in Case 2 damps the inter area modes and rotor speed transient oscillations effectively. The presence of DFIG in the 3rd case causes a major impact on the small signal stability by affecting the inter area oscillatory modes which in turn lead's to dynamically unstable behaviour of the system.

This negative impact can be solved by Case 4 by employing AVR and PSS to the remaining generators, which improves the damping ratio in local and inter area oscillation modes, thereby ensuring the stability.

In Case 5, DFIG partially replaces the generator in each step increase. The step increase is given at the rate of 100 MW. The generator is completely replaced by DFIG when the wind power penetration level is at the rate of 800 MW. Until reaching 800 MW, damping ratio is not much appreciable for inter-area modes of operation. Even at the rate of 500-800 MW, the damping ratio of local area modes of oscillation also does not show an effective performance.

When the penetration level goes higher there is a better damping in the modes of oscillation. It is observed that once the penetration level reaches to 800 MW, the DFIG completely replaces the generator and the results obtained at that time is similar to those obtained in case 4.

Later comparison of the performance of a hybrid power system (HPS) in steady state verses faulty condition with and without battery and excitation systems are designed and explored by Lin ye et al in [32].

The HPS model consists of wind turbine, PV arrays and a hydro turbine. The PV node is connected with a battery and hydro turbine is connected to automatic excitation system. All these sources are modelled in EMTP/ATP software package. Droop control algorithm, active power/frequency, reactive power/voltage droops are adopted for PV interfaced inverters. It is observed that at steady state the voltage and frequency remains constant.

When a three phase fault is created at a particular time interval, the terminal voltage drops down heavily in all microsource and severe voltage sag is experienced. In order to maintain the stability, the sources are said to decrease the active power and increase the reactive power. But this is not effective from stability point of view. These effects can be mitigated by battery backup and automatic excitation systems.

When fault occurs the battery is included in simulation after a few cycles and it provides real power gradually increasing the terminal voltage. Similarly instead of giving a constant excitation current to the hydro turbine, the automatic excitation system helps to improve the terminal voltage, by adjusting the excitation current. Thereby satisfying the objective by maintaining the system transient stability.

6. Conclusion

The significant development in the microgrid has expressed concern over transient problems which jeopardize the system stability. This article had surveyed various hindrances that occur in microgrid owning to inverter interfaced DG, wind power plants, islanded microgrid and hybrid microgrids. The basics of transients stability and its issues were discussed .In this work, research articles proposed under transient stability is attentively reviewed and further an extensive study analyzing the challenges is stability are listed in every subsections. .In the researcher's attention, this literature review will be valued as a citation to the work in the field of transient behavior in microgrid.

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