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Non-Adaptive Control Technique for Voltage Regulation with Distributed Energy Resources

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Abstract:-The revolution is in a beginning stage of traditional large central power stations. Transmission and distribution grids are now used by independent power producers to supply power. With the increase in use of distributed energy system in industry and its technical improvement, it is becoming more important to understand the integration of these systems with grids. Ancillary services provided by the distributed energy resource (DER) along with facility of cogeneration compensates the installation cost and make it affordable. Voltage regulation problem and its mitigation by using power electronics interface is discussed in this paper. Voltage regulation is studied with the change in loading level and controller gains in developed MATLAB Simulink model.

Keywords:-Distributed energy resources (DER), distributed generation (DG), ancillary services, hybrid system, voltage regulation.

I. INTRODUCTION

Electric energy consumption is greatly increasing day by day and at the same time fossil fuels are depleting rapidly. In such challenging condition centralized generation is not enough for providing necessary power. To deal with such scenario environmental friendly distributed generation systems must be developed and used at distribution sides, which can be vital solution to this challenging condition. Distributed Energy Resources provides a wide range of non-active power related ancillary services such as voltage control, load following, network stability, peak shaving, spinning reserve, back-up supply, seamless transfer, harmonic compensation [1, 2, 3, 4]. With these ancillary services it also provides space heating, absorption cooling and cogeneration.

There are different technologies of distributed energy resources and each one has its different characteristics. They have various advantages and disadvantages over each other. To obtain optimum benefits from distributed energy resources proper techniques of interconnection must be developed ensuring that the system stability and reliability must be maintained.

Voltage and frequency of system should be at a desired level to maintain the power quality of system. Reactive power plays vital role for maintaining system voltage at a desired level and solve voltage control related issues faced by power system [5]. Due to local voltage collapse it is difficult to maintain voltage at specified level. Local voltage collapse can lead to a major blackout. Power electronics gears are used to maintain reactive power and it also provides ancillary services as it consists of advanced semiconductor technology, microprocessors and provides quick response [6]. PI controller is used because of its simplicity and robustness. But practically it is challenging task to set gain parameter of PI controller and improper value cannot give the desired response.

This paper is organized as follows; section II describes distributed generation in brief with definition, its type, ancillary services provided by distributed generation as shown in figure 1 and interconnection of distributed energy resources Section III presents the system used for voltage regulation and non-adaptive control scheme. Section IV explores the performance analysis and effect of controller gain parameters on regulation. Section V presents conclusion.

II. DISTRIBUTED GENERATION

A. Definitions of Distributed Generation

Concept of distributed generation is not unique but in latest years it catches more attention because of its benefits and reduced CO_2 emission which makes it acceptable. Distributed generation is defined by various organizations.

The IEEE defines the DG as generation of electricity by facilities sufficiently smaller than central plants, usually 10 MW or less, so as to allow interconnection at nearly any point in the power system. On the basis of above standard definition and definitions surveyed [7]DG can be summarized as “It is an electrical power source smaller in size which is connected to distribution side to open its benefit to end user”

B. Types of Distributed Generation

Many distributed generation technologies are under development and in early phase of commercialization. On the basis of numerous things we can classify the established DG such as available unit size, capability of emission free operation, technology used and location of its connection. But usually DG is classified according to operating technology and unit size. Photovoltaic technology and wind energy conversion technique catches more attention because solar and wind energy are widely available worldwide. Global installed capacity of solar PV is reached up to 277 GW with an increase of 50 GW in the year 2015.

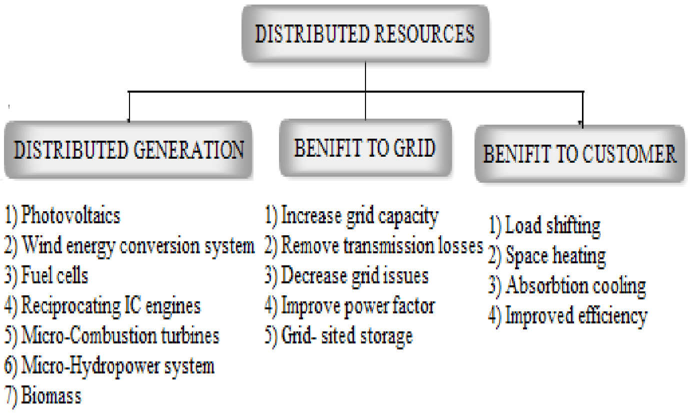

Fig.1. Distributed resource

In India total installed capacity of solar PV is 4878.87 MW whereas United States is leading country in investment and generation of wind energy in 2015 and global installed capacity is 433 GW [8]. In India total installed capacity of wind power is 25088.19 MW. By using high temperature fuel cell in combined heat and power technology make system more efficient and acceptable as it provides space heating and absorption cooling [9]. Micro-combustion turbines or gas turbines work on similar principle. 30 to 75 kW micro-turbines are used for commercial applications [10].

Micro-hydropower systems are considered to be those which had generation capacity smaller than 100 kW. Simplest micro hydro plants doesn’t include dams they are simply run of the river system. The overall installed capacity of micro-hydro electricity generation in India is 4176.82 MW. Biomass plants works on principle of Rankin cycle and total installed capacity in India is 4550.55 MW.

Storage is important in the micro-grid both because tariff are higher during peak load so it is expensive to serve with purchased power also in islanded mode to maintain continuity of supply during disturbance. Lead acid battery, supercapacitor, flywheel are used for storage purpose.

C. Hybrid System & Combined Heat and Power (CHP) in Distribution Generation

Electricity demand is increasing day by day so as to fulfil the requirement of customer, it is essential to increase generation capacity. Expansion of already existing grid can cause congestion. Therefore small generating technologies are to be interconnected. Also many generating technologies depend on weather conditions and have different characteristics so failure of one can be compensated by other. Integration of heterogeneous distributed resources with power system is done by using DC link, AC link and synchronous link [11]. At same time connection of distributed generators on large scale to the distribution feeder develops system protection issues. Fault magnitude in system increases as new generating sources takes entry in the system. The important power system concerns which originates because of DG interconnection are desensitization of relay, nuisance tripping, auto-reclosures, neutral shift, unintentional islanding and resonance condition [12]. Protection scheme should be able to disconnect DER from distribution grid under diverse situations. Protective relay compulsorily disconnect the generator when feeder is not getting supply from utility, system originatesdisturbance, shunt fault on the utility network and abnormal condition. DG must follow the interconnection requirements of IEEE 1547 [13] and CPUC Rule 21.

Cogeneration can be possible from some generating technologies which help to increase system efficiency and make it viable. Some distributed generation techniques produces usable heat while generation of electricity such as fuel cell, combustion turbines. This produced heat which can become a key factor to enhance the economics of DG technology greatlyby utilizing it and making it viable. This waste heat can be utilized for various applications depending on their temperature levels. CHP system typically provides high temperature heat which can be utilized in industry for various procedures, on-site space heating as well as absorption cooling.In evaporation portion shown in figure 2 refrigerants absorbs heat from system and provide absorption cooling [9, 14].

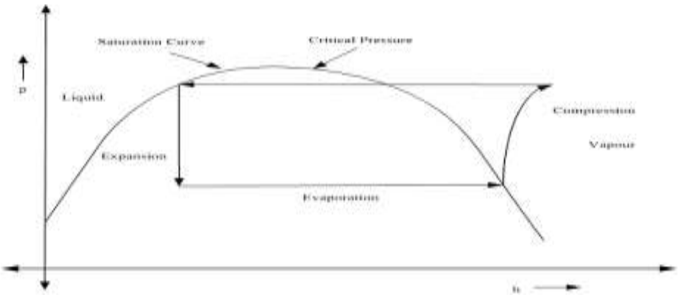

Fig.2. Vapour compression refrigeration cycle

III. SYSTEM DESCRIPTION

To study voltage regulation for change in loading level and controller gains with integrated distributed energy resources a model is developed in MATLAB Simulink. A three phase 415 V (L-L) AC source is feeding a three phase load of 35kVA 0.8 p.f. lagging. The phase to neutral voltage is 233.56 V which is considered as a reference voltage (V_t^*). Source resistance (R_s) and source inductance (L_s) is taken as 0.04 Ω and 0.5 mH respectively. Voltage source converter is connected in parallel with grid at point of common coupling (PCC) through coupling inductors L_c as shown in figure 3. Voltage at PCC is denoted by V_t. Any of these distributed energy resources such as photovoltaic, wind energy conversion system, fuel cell, IC engines, micro-turbine etc. can be used at DC side of this voltage source converter. In this model PV, wind energy conversion system and fuel cell are integrated on DC side of converter. Switching frequency of inverter is taken as 10 kHz. The regulation of PCC voltage depends on reactive power. Voltage source converter maintains the voltage to V_t^* by supplying or absorbing reactive power.

DC side voltage of inverter is calculated as

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m}$$

Where, m is modulation index, V_{LL} is AC line output voltage
Hence value of DC side voltage of inverter is 700 V.
Coupling inductor L_c is is evaluated as follows

$$Lc = \frac{\sqrt{3} * m * V_{dc}}{(12 * a * f_s * i_{ripple})}$$

Where, $f_s$is switching frequency, a is overloading factor, i_{ripple} is ripple current.
Value of coupling inductor is calculated and found to be 2.25 mH.

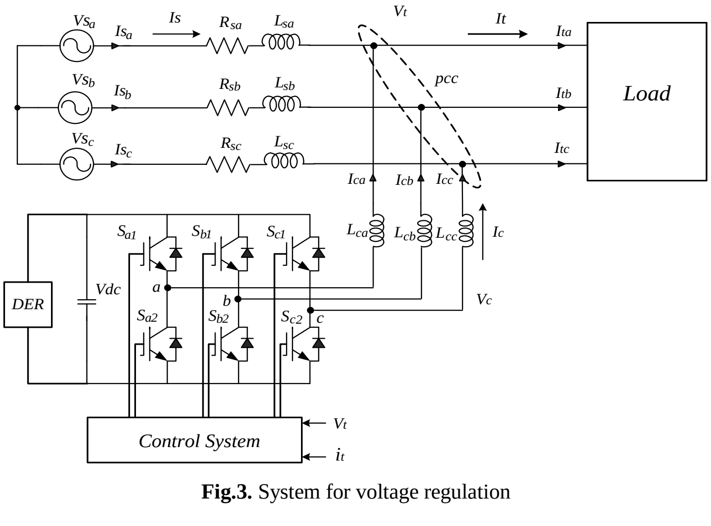

Fig.3. System for voltage regulation

` Precision of regulation in compensation system depends upon control algorithm which generates switching signal of voltage source inverter. Voltage drop in system can be compensated by various techniques such as sinusoidal pulse width modulation, hysteresis control and P-Q theory based techniques [15].

In this model sinusoidal pulse width modulation with proportional integral (PI) controller is used because it is simple to implement and produce appropriate switching signals. To maintain system voltage at desired level control scheme is shown in figure 4. Voltage at point of common coupling is converted into RMS value and then it is compared with reference voltage V_t^*. After comparison it generates error which is given to PI controller. By setting the proper values of proportional gain (K_p) and integral gain (K_i) output voltage V_c^* of compensator is generated. The output of compensator is used to generate PWM signal to drive the inverter.

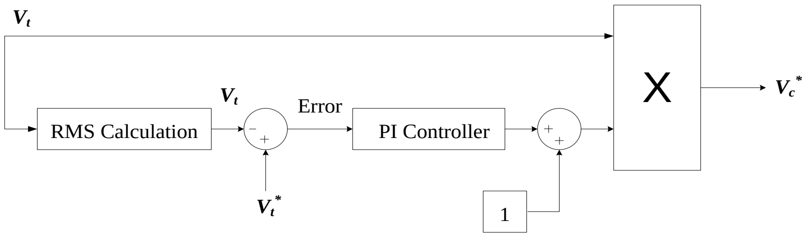

Fig.4. Control scheme for voltage regulation

If load changes then we have to tune the controller parameters again to obtain desired voltage therefore it is known as Non- Adaptive control scheme. Control scheme can be expressed in form of equation as follows

$$V_t^* = V_t(t) + V_t(t)K_p[V_t^*(t) - V_t(t)] + V_t(t)K_i \int_0^t [V_t^*(t) - V_t(t)]dt$$

A MATLAB model based on figure 3 is simulated by using Sim Power System toolbox as shown in figure 5. Simulation time is assumed as 3 sec with sampling period of 5e^{-05} sec. Subsystem of distributed energy resource block contains integration of solar, wind energy conversion system and fuel cell.

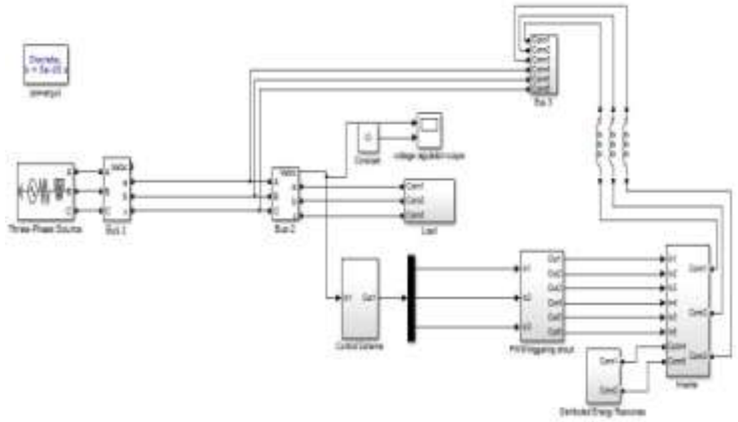

Fig.5. MATLAB based simulation model for voltage regulation

IV. RESULTS AND DISCUSSION

The performance of sinusoidal pulse width modulation technique with PI controller for voltage regulation is simulated for different gain parameters and loading levels and the results are discussed below.

A. System without Compensation

Load of 35kVA with 0.8 p.f. lagging is connected in system which gives desired voltage level of 233.56 V. This reference voltage is shown by straight green line. At 0.33 seconds 80% of 35 kVA load is increased suddenly i.e. 28 kVA load with 0.9 p.f. lagging is switched into the system. Due to this additional load it consumes reactive power which reduces the voltage level to 228.85 V and creates voltage drop of 4.71V. Actual reduced voltage is shown by blue line. System voltage without compensation is shown in figure 6.

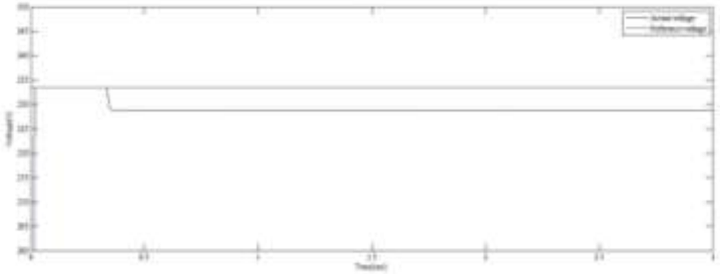

Fig.6. Drop in system voltage due to increased load

B. System with Compensation

Before addition of extra load system voltage is maintained at desired level of 233.56 V which is reference voltage. After addition of load it reduced to 228.85 V up to 0.66 seconds as compensation is not provided from 0.33 to 0.66 seconds. After 0.667 to 1.144 seconds compensation is carried out and voltage source converter provides the reactive power. Due to this reactive power system voltage get boosted and reached to the desired level of 233.56 V. After 1.114 seconds system voltage is maintained at 233.56 V as shown in figure 7.

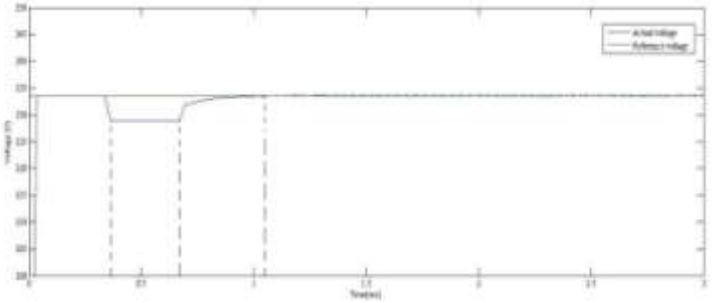

Fig.7. System output after voltage regulation

C. Effect of Controller Parameter on Voltage Regulation

Voltage regulation is depends upon gain parameters of PI controller. Gain parameters PI controller must be in particular range otherwise it will produce improper switching signal for converter and system voltage cannot reached to desired voltage level. If the values of K_p and K_i are not properly set then it results into oscillation, overshoots and slow response.

When K_p=0.53 and K_i=0.915 after providing compensation also it produce oscillations and voltage does not settle to desired level as shown in figure 8. When K_p =0.0248 and K_i=0.036 slow response is obtained due to small values of K_p and K_i as shown in figure 9.

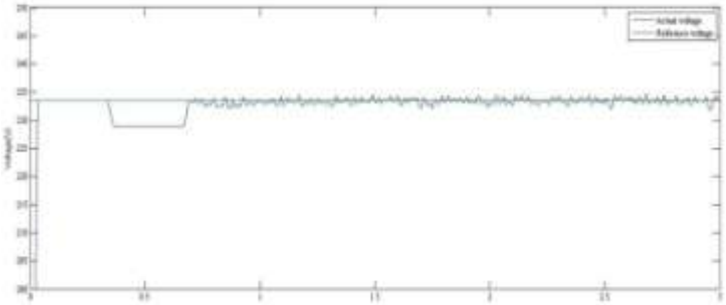

Fig.8. Oscillation produced in system voltage

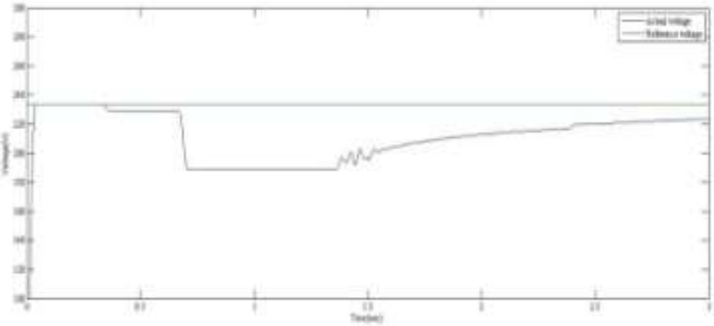

Fig.9. Voltage regulation with small value of compensator gain

D. Effect of Variation in Load on Voltage Regulation

In any electrical grid system, load is continuously changing. This change in loading level affects the voltage regulation as reactive power necessary for compensation changes according to loading level. The gain values set for previous loading condition are not valid for change in the load. Previously system was loaded with 35 kVA and additional load of 28 kVA. For this situation we regulate the voltage from 228.5 V to 233.56 V with gain parameters K_p=0.0627 and K_i=0.846.

Now system is loaded with additional load of 57060 W+ 27635.4193 VAR. So this change in load causes system voltage to drop to 224.735 V as shown in figure 10. Now for this change in load if gain parameters of controller are not tuned then voltage regulation is not properly performed. Due to improper values of gain parameter voltage doesn't settle down to 233.56 V as shown in figure 11. PI controller should be tuned again for this change in load to supply required reactive power for compensation to get desired response. When controller gains are set as K_p=0.072 and K_i=0.87 then voltage drop is compensated and voltage will settle down after 1.5 second. Controller takes 0.66 to 1.5 second for regulation of voltage as shown in figure 12.

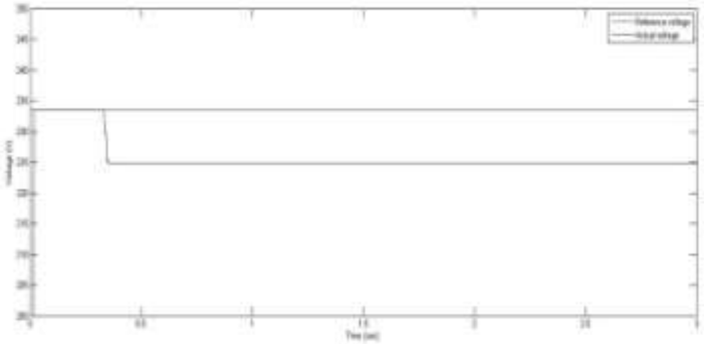

Fig.10. Voltage drop due to increase in load

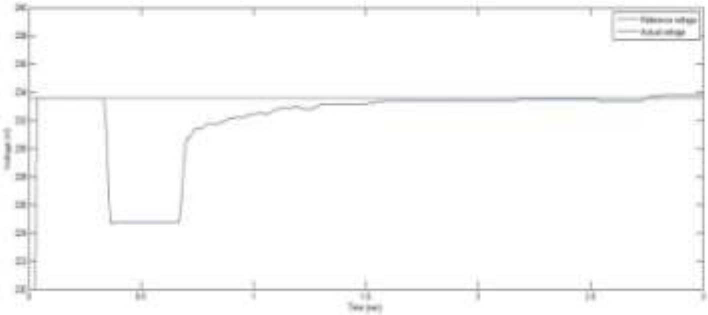

Fig.11. Improper voltage regulation due to improper controller parameter

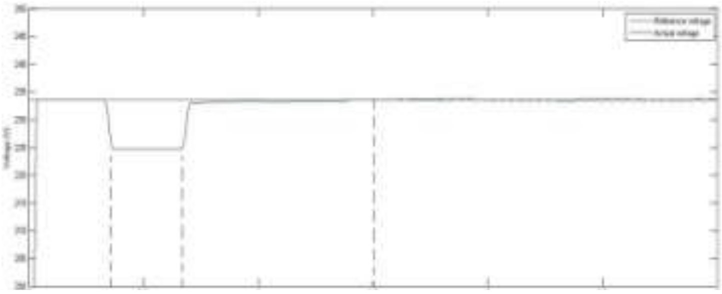

Fig.12. Voltage regulation with proper controller parameter

V. CONCLUSION

It is now widely accepted that use of renewable distributed energy resources is a solution for conservation of fossil fuels as well as to reduce the pollution. Also combinations of two or more DG are necessary to satisfy customer demands as a characteristic offered by every DG is different. By providing wide range of ancillary services power quality can be improved. Voltage regulation can be achieved by using Non-Adaptive control scheme but setting of K_p and K_i value is difficult task. K_p and K_i determines the system response therefore only precise values gives the desired output. Controller gain parameter changes with loading level. Supplementary intelligence techniques is necessary to change the parameter of controller according to change in distribution system conditions. Therefore for better regulation adaptive system with communication facility should be developed.

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