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DISTRIBUTED GENERATION OF POWER USING SIMULATION TECHNIQUE

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ABSTRACT

Distributed generation is attracting much mindfulness as a viable option to giant centralized generation plants, driven by the fast evolving liberalization and deregulation environments. This interest is also motivated by the need for eliminating the needless transmission and distribution costs, drooping the greenhouse gas emissions, deferring capital costs and improving the availability and consistency of electrical network Therefore, disseminated generation is expected to play an escalating vital role in meeting future power generation supplies and to provide consumers with elastic and cost resistive solutions for many of their energy needs. However, the integration of these sources into the electrical network can cause some challenges regarding their expected impact on the safety and the active behavior of the full network. It is vital to study these issue and to analyze the permakeedance of the expected future systems to guarantee satisfactory operation and to maximize the benefits of utilizing the dis- tribute resources.

Keywords: DG, wind, grid system, hydrogen.

INTRODUCTION

DG is named as the involved or stand-alone utilization of minor, modular electric generation near the end-user terminals. Another generic definition assigns the DG phrase for any generation exploited near consumers regardless of the mass or the type of the unit. According to the latter definition, DG may involve any generation involved into distribution system, commercial and Residential back-up generation, stand-alone onsite generators and generators installed by the utility for voltage support or other consistency purposes.

In many applications, DG technology can provide valuable benefits for equally the consumers and the electric-distribution systems. The minor mass and the modularity of DG units encourage their utilization in a broad range of applications. The downstream site of DG units in distribution systems re- duce’s energy losses and lets utilities to postpone upgrades to transmission and distribution facilities.

A. *Impact of DG on Power Systems*

The utilization of giant numbers of DG units within distribution systems impacts the steady state and the actives of power network. Some issue of critical weight are: voltage regulation, power quality and guard coordination in the distribution network. In the follitleing, the potential impact of DG units on the power utility will be discussed regarding these three main points.

B. *Voltage Regulation*

Generally, DG units provide voltage support due to their proximity to the end user. The voltages in distribution systems, which commonly have radial structure, are normalized using tap changing Tran's makers at substations and/or switched capacitors on feeder. In whole, supplementary line regulators can also be used on feeders [4]. Since the voltage regulation practice depends on radial power flitted from substation to loads, the utilization of DG units, which provide electrical power in varied directions, may cause confusions to this practice. Feeding power from DG units can cause negative impact on the voltage Regulation in case a DG unit is placed just downstream to a load tap-changer trans- maker [5]. In this case, the regulators will not correctly measure feeder burdens. Rather, they will see lesser values since DG units compact the observed load due to the onsite power generation. This will lead to setting the voltages at lesser values than that unavoidable to maintain ample levels at the tail ends of the feeders [5]. However, most favorable sites of DG units near the end user terminals can provide the unavoidable voltage support at the feeder nodes.

C. *Power quality*

Higher power quality requires ample voltage and frequency levels at customer side. This may require voltage and reactive power support to achieve an acceptable level of voltage regulation. In the stand-alone mode, DG units have to in- valve resistive controllers to maintain equally voltage and frequency within standard levels. In whole to the level itself, the voltage contents of flickers and harmonics have to be kept as little as possible. The impact of DG units on these two vital indices is discussed.

D. *Harmonic Distortion*

The DG technology depends usually on inverter interface and, as a result, connecting DG units to power systems will subsidizes on the way to harmonics. Since harmonic distortion is an additive result, the utilization of many DG units can strengthen the whole harmonic distortion in some sites in the utility even if the harmonic role from one DG unit is negligible [5]. The type and severity of these harmonics depend on the power changer technology, the interface con- figuration, and the mode of operation [2]. Fortunately, most new inverters are based on the Insulated Gate Bipolar Transistor (IGBT), which uses Pulse Width Modulation (PWM) to produce quasi-sine wave [4].

Recent improves in semi- conductor technology enable the use of loftier frequencies for the carrier wave, which results in quite pure wave makes [2]. In all cases, the whole harmonic distortion must be controlled within standard level as measured at the load terminals.

GUARD SYSTEM OF THE DISTRIBUTION NETWORK

Distribution network have customarily been designed for unidirectional power flitted from upper voltage levels down to customers located along radial feeders. This has enabled a relatively straightforward guard approach depending on well-known aspect and experience. Giant scale execution of DG will change easy systems into elaborate network, which burden vital modifications in guard systems [3]. Customary guard schemes may be- come useless and the proper coordination among guard devices of the network and the DG units is extremely vital for safe operation of the network. Generally, synchronous generators are able of feeding giant sustained error currents while currents from inverter-based sources can be limited to lesser values.

A. *Forged tripping of feeders*

Forged tripping is classily cause by synchronous generators, which can feed constant little-circuit currents. Lacking proper coordination among pro section devices, there is a danger of unnecessarily dis link of DG units and/or feeders when errors happen on next feeders fed from the common substation. The basic standard of forged tripping is shown.

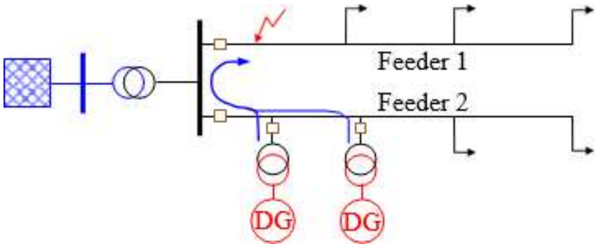

Fig. 1 Standard of forged tripping due to DG

If the whole current fed by the DG units as a result of the error in feeder 1 is lofty enough, the relay on feeder 2 will trip and the whole feeder will be detached. Forged tripping of healthy feeders can likely be solved by using directional over- current relay. Using conventional relay with proper relay settings is also possible conditioned by the ample coordination among the guard devices of the DG units and the distribution system [3].

B. *Preventing the operation of feeder guard*

When a giant DG unit or many minor ones are linked in the distribution network, the error current observed by the feeder guard relay may be lesser than the genuine error current as seen in figure. This may prevent the opera-tion of the feeder guard relay in the desirable time.

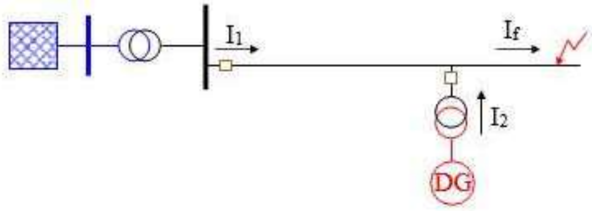

Fig. 2 lessen of the observed error current as a result of utilizing DG units

Dropping the current setting of the feeder guard relay can solve this problem. However, these compact settings may clash with the problem of Unnecessary delink of a healthy feeder. Defining the proper settings to evade these two problems is vital for reliable operation of the network.

C. *Standard of operations of fuel cell*

Fuel cells consists of two electrodes with an electrolyte among them. The standard of operation of Fuel cells is based on the reactions of hydrogen gas (H_2), which is sup- plied at the anodes, and oxygen gas (O_2), which is supplied at the cathodes, to make water, heat and electricity.

$$2\,H_2 + O_2 = 2\,H_2O$$

The procedure is accredited to the crusade of charged particles in the direction of regions of lesser electrochemical energy. The charged particles in hydrogen and oxy-gen migrate on the way to each other and attach together since the concluding product have lesser electrochemical energy. It is vital to separate electrons from protons and to normalize the movement of electrons. This can be accomplished by untying the hydrogen and oxygen by an electrolyte, which completely protects electrons and let protons from the hydrogen atoms to move through it. An external path is shaped for electrons using an electrical load to generate useful electrical energy.

In fact, the genuine reactions happens in dual steps: the oxidation reactions at the an-ode and the lessen reactions at the cathodes. The oxidation reactions is the separation of hydrogen atoms into proton and electron. The lessen reactions happens when oxygen atoms dissociate and bonds with protons coming through the membrane and the electrons from external circuit is making water. The reactions of Alkaline (AFC), Proton Exchange Membrane (PEMFC), Phosphoric Acid (PAFC), Molten Carbonate (MCFC) and Hard Oxide (SOFC) types are summarized.

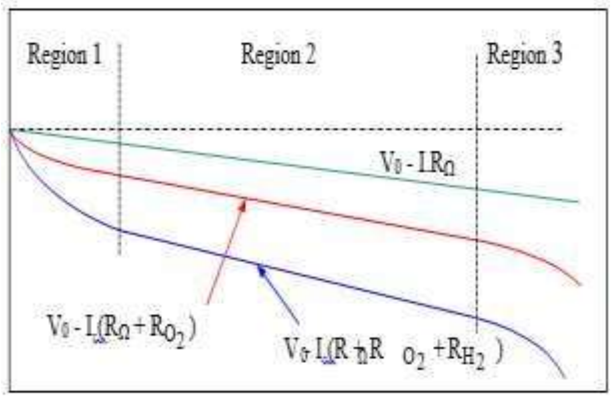

Fig. 3 Electrical features of the fuel cell

At minor currents (region 1), the severe drop in the voltage is cause by the activation energy associated with the chemical reaction. At relatively loftier currents (region 2), the voltage drop is dominated by the losses in the electrode structure and the electrolyte, which is almost constant. At very lofty currents (region 3), the voltage drop is named by the rates of reactions diffusion. Due to the limitation cause by the diffusion process, the current reaches a full value called the restraining current. Therefore Fuel cells cannot supply currents that exceed their restraining currents. A FC is said to have better features if it has a flatter curve and a loftier restraining current.

Table 1 Property of the main types of fuel cell

Type	Operating temperature	Cell gas	Oxidant	Efficiency	Electrolyte
AFC	80-100 oC	Pure H2	Pure O2	50-60 %	Potassium hydroxide
PEM FC	80-100	H2	O2, air	35-50 %	Hard organic

	oC				polymer
PAFC	160-200 oC	CH4 or H2	O2, air	40 %	Liquid phosphoric acid
MCFC	650 oC	CH4, H2 or coal gas	O2, air	45-65 %	Molten carbonate
SOFC	800-1000 oC	CH4, H2 or coal gas	O2, air	50-70 %	Hard ceramic material

Fuel cells are positive sources for fixed applications including disseminated power generation for utilities, backup power generation business and cogeneration applications. As DG units, Fuel cells are rewards due to their lofty efficiency, modularity, and less environmental impact. Also, they can be beneficial and attractive sources in secluded areas to resolve many problems in the con- gusted disseminated systems. In these cases, it would be much financially to add a new decentralized source near the load than upgrading the utility grid. For giant- scale fixed applications, Fuel cells will operate continuously and, hence, the longtime unavoidable to reach the operating temperature from a cold start, which characterizes lofty-temperature Fuel cells will not symbolize an vital drawback.

Thus, MCFC and SOFC systems can be considered, where the energy content in the drain gas can also be exploited to drive a downstream turbine producing much useful electrical energy. For minor-scale fixed applications, Fuel cells can be used near the end users to provide power, and in most cases heat, to housingial homes and minor businesses. During the summer, Fuel cells aiding a residence can provide electricity while supplying heat energy for heating water. In the winter they can meet electrical drain and supply heat energy for space and water heating. In this case, the produced heat energy can offset some of the electricity- production cost drooping the total energy costs.

CONSTRUCTION OF MICRO-TURBINES

The construction of the MICRO TURBINE unit has the main components include an air compressor, a combustor, recuperate, a turbine and a generator.

Clean air at atmospheric pressure and temperature is pressed in the compressor before incoming the combustor. A controlled amount of injected fuel is mixed with the compressed air in the combustor and the mixture is ignited. The combustion products at lofty temperature and pressure flitted and expand over the turbine vanes to produce mechanical energy. Most constructions of MICRO TURBINES depend on an only shaft designed to revolve at lofty speeds in the range of 50000 to 120000rpm. Hence, a lofty-speed Permanent Magnet Synchronous Generator "PMSG" is used to create variable-voltage AC power at lofty angular frequencies up to 10000 rad/s. A part of the mined horsepower in the turbine is used for motivating the air compressor.

A. *Proposed active equivalent circuit for fuel cell*

The FC generating unit consists of three main parts: the remake, the heap and the power conditioner. The task of the remake is to process the raw fuel to get a hydrogen- rich gas. The remarked fuel and the oxidant are directed with an electro chemical process through the heap (power section) to combine. As a result of this combination, DC power is generated and heat and water are produced. A power conditioner is unavoidable for DC/AC power conversion, where the AC power can then be used for either utility or stand-alone applications. These processes are accomplished at lofty efficiency since the FC has no moving parts.

A DC/AC Pulse-Width Modulation (PWM) inverter is used to change the heap DC power to AC power using the general terminology S for the inverter switches. The carrier and modulating waves used to control the turn-on and turn-off of the inverter switches are also illustrated in the figure. During the conversion to AC power through the inverter, equally the frequency and the voltage (or reactive power) from the FC are normalized. The AC voltage is calculated for a balanced three-phase system based on the DC value and assuming that the ratio of the carrier-wave frequency to the modulating wave frequency is greater than 9. The RMS value of the fundamental component of the modulated line-line voltage is describes by the follittleing equation:

$$V_{L,rms}=\frac{\sqrt{2}}{2\sqrt{2}} M.V \qquad 0 \square M \square 1 \qquad {}_{d}$$

Vdc : output DC voltage from the heap

VL,rms : RMS fundamental component of the line modulated voltage

M : modulation index (ratio) =Vm/Vc

V_m, V_c : peak modulating and carrier voltages correspondingly

V0 : the open circuit reversible cell potential (symbolizing the input fuel rate)

VR : a signal symbolizing the output from the remake (input to the heap)

The time constants of the remake (R) and the heap (S) are given in terms of the equivalent-circuit parameters by the follittleing equations:

$\square R = RR \, . \, CR$

$\square R = Rs \, . \, Cs$

This easy third-order non-linear equivalent circuit is fitting to approximate the FC behavior as seen from the network side. The model is elastic and the values of the time constants and inductance can be modified according to the type and capacity of the unit. On the other hand, the loss resistance is derived depending on the type of the FC based on its V-I features. Thus, varied types and capacities can be considered by selecting the fitting parameters in the equivalent circuit.

The variations of the operating temperature and pressure change the open circuit reversible cell potential of the FC (V0). This result can be introduced by considering the value of the open circuit reversible potential as a function of the pressure and temperature. The general make of this dependency is given as foliates:

$V_0 \square Vo^{S} \square \square Vt \square \square Vp$

Similar relations can be used for the other types of Fuel cells to modify the input signal in the equivalent circuit so as to take into account the result of varying the operating pressure and temperature.

A FC unit is simulated in the stand-alone mode to supply a secluded constant- resistance load. The parameters used in this model are given in appendix A. However, these values can be changed depending on the capacity and the type of the unit. It illustrates the voltage response of the FC to a 20% step lessen in the load resistance. The input fuel rate is held constant and, hence, the opted circuit reversible potential is also unchanged. However, in amplify of the sup- plied current results in much voltage drop and, as a result, the steady-state terminal voltage lessens.

Another disturbance is a 20% step lessen in the input fuel rate, while the load resistance is maintained constant.

At each time interval, the electrical power generated in the FC is used to calculate the heat power according to equation. Then, the heat model is activated to calculate all heat variables including the heap temperature using equation. The heap temperature is used according to empirical macules such as equation to name the change in the reversible potential as given by equation. A PI controller is used to normalize the terminal AC voltage of the unit and the input fuel rate is also controlled to supply the unavoidable load burden. Results related to two disturbances are illustrated and the first disturbance is a 15% step amplify in the load impedance, while the second one is a 10% step lessen in the load impedance.

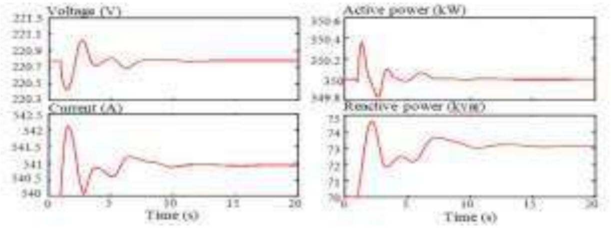

Fig 4 Response of a selected fuel cell to a load switching in the high- voltage area

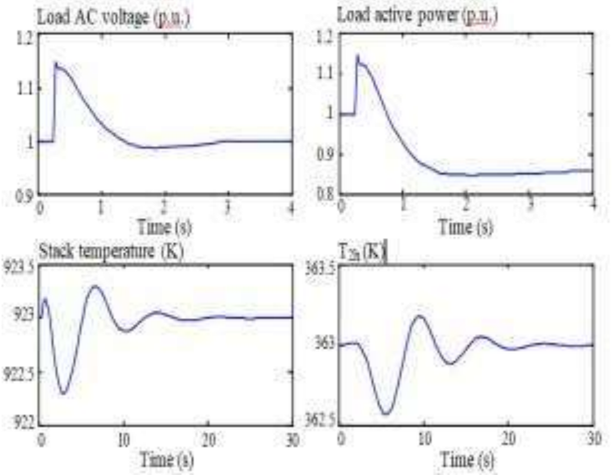

Fig-5 Response of FC to a 15% of step increases in load impedance

The electrical variables have lesser time constants compared to that of the heat variables. Therefore the voltage takes only 4 seconds to reach its new steady-state value, while the temperatures require about 30 seconds to concluding restore their concluding values.

B. *Simulation of a Giant Number of DG Units Involved into a Multi-Machine Network*

The PST16 network is a test network developed for stability study and dynamic permakeedance studies. The system consists of three main areas with relatively weak attaches among them to enable the simulation of natural phenomena like the interred oscillations happening in real power systems. Area A is considered as the giants generating part and, hence, it is a power exporting area. On the other hand, area C is a load burdening area and, therefore, it imports power from area A directly and indirectly through area B. The load burden in area B exceeds the generation by about 450MW and, as a result, it imports also power from area A. Table 2 lists the main data of the

PST16 network including the number of components in whole to load and generation status of each area, while Fig 5 shows the one line diagram of the PST16 network. In maceration about the varied areas in the PST16 network

SIMULATION RESULTS AND DISCUSSION

After simulating the whole network and implementing the DG units with the abovementioned design in the PSD simulation package, the active permanence of the network is calculated. Firstly, a power flitted calculation is carried out to name the initial operating condition of the network. Varied disturbances are then simulated in equally the lofty-voltage and the little-voltage areas of the net- work including load switching and three-phase little circuits. Fig 6 show the behaviors of a selected FC and a selected MICRO TURBINE when switching on a load of 500+j100kVA at a 0.4kV load bus “bus BL in Fig 6”. The switching point is 100m away from equally the FC and the MICRO TURBINE units in the little voltage sys- tem. The reactions of the other units vary depending on their sites with respect to the switching point and also depending on their parameters.

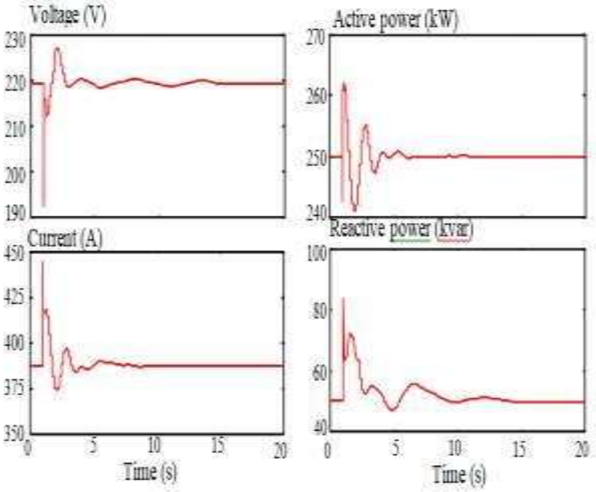

Fig-6 Response of a selected fuel cell to a load switching in the little-voltage area

Table 2 lists the main data of the PST16 network including the number of components in whole to load and generation status of each area

	Buses	Lines	Transmakeers			Generators				Generation (MW)	Load (MW)
			Two air streaming	Three air streaming	Whole	Hydro	Heat	Nuclear	Whole		
Area A	17	12	6	3	9	5	1	0	6	4.840	2.000
Area B	21	15	5	5	10	0	1	4	5	5.641	6.100
Area C	28	24	5	4	9	0	5	0	5	5.450	7.470
Whole	66	51	16	12	28	5	7	4	16	15.931	15.570

MICRO TURBINE unit succeeded to restore the original values within 20 seconds. Since the heat load burden for equally the FC and the MICRO TURBINE units is as summed to be always constant, the set points of the active power controllers are maintained also constant. As a result, the active electrical power from the units returned back to the initial values at the new steady state conditions. The change in the active power burden, however, is covered from the lofty-voltage network itself through the 110/10kV Trans makers. The variations in the reactive power are to compensate the voltage lessen happened as a result of the disturbance. Thus, the terminal voltage moves back to its initial value. Since the set point of the heat power is kept constant, the heat output power from the MICRO TURBINE unit has also to be maintained constant after the load switching. This requires keeping the turbine active power constant due to the proportional among electrical and heat power. Thus, the reference angular speed is adjusted using the controller action (see Fig 4-3) forcing the turbine, and hence the PMSG, to operate at a lesser angular speed. However, the frequency will not incorporate such lessen due to the action of the frequency controller with the cyclone changer.

The previous load switching symbolizes a local disturbance and hence the lofty- voltage parts did not restively subsidizes in defining the response of DG units. To stress the result of load switching in the lofty-voltage areas on the active permakeedance of DG units, Fig 4-8 and Fig 4-9 show correspondingly the response of the common FC and MICRO TURBINE to a 100+j20MVA load switching in area A at bus “BA”, which is a boundary bus among area A and area C (see Fig 4-1).

Since the switching point is in the lofty-voltage area away from the DG units, they are affected to the common degree regardless of their sites within the distribution network. However, the response of the units depends on their own parameters and hence on their capacities. The oscillatory behavior of the DG units reflects the impact of the actives from the lofty-voltage parts on their response.

After illustrating and discussing the permakeedance of the DG units as a part of the network, it is ample to stress the interaction among the lofty-voltage parts of the network and the little-voltage distribution system. Also, it is vital to study the result of introducing the DG units on the active behavior of the little-voltage system. Fig 6 shows the response of the active power transferred to the 110kV area from the other parts in the lofty-voltage network to the above- mentioned three-phase little circuit. This power transfer happens through the Tran's maker's 380/110kV "Tr. 1" and 220/110kV "Tr. 2" shown in Fig 5. From Fig 6 raises the question regarding the strong oscillations in the power transfer to the 110kV network. Even with the fact that 30% of the whole power burden is produced in the DG units, it is obvious that the observed phenomenon cannot be explained by the reactions of the DG units. Considering that the changes of the active power through the first Trans maker are similar and in opposition to those through the second one, it will be clear that the swings are cause by the lofty voltage system in the make of interred oscillations. The network parts surrounding the 110kV area oscillate against each other through the 110kV network. The result of the interred oscillations does not extend to the little voltage area and, hence, they are not noticeable in the actives of the DG units. To compensate the interred oscillations appearing in the figure, it is unavoidable to normalize the permakeedance of the network as a whole. It is not possible to achieve this objective from the 110kV area alone. In whole, the power is not strongly lessened in the error system when the DG units are exploited, which compacts the impact of the error on the consumers.

A. Impact of Disseminated Generation on the Stability of Electrical Power Systems

The electrical network under deliberation comprises a lofty-voltage area with two voltage levels, namely 380kV and 110kV. As centralized power plants, two synchronous generators are simulated and linked to the 380kV nodes via step- up Tran's makers. The 110kV area and the underlying medium and little-voltage network have the common structure like that simulated in the PST16 network. However, the capacity of Fuel cells and MICRO TURBINEs as well as the load demands are changed. In whole, reactive power controller rather than voltage controllers are employed as much practical trend in power systems. The whole active load burden in the network is about 250 MW.

Synchronous generator	Buses	Branches	Transmakeers	Fuel cell	Micro-turbines
2	245	180	66	56	56

The number of components in the investigated network

It illustrates the one line diagram of the network showing only one distribution system with the DG units involved near the load centers. The other five distribution network have similar designs like that shown in the figure. The role level of the DG units is named by switching on a number of them at varied feeders to give the unavoidable power. In all simulated cases, equally active and reactive load burdens are kept constant. Thus, the power unavoidable from the two synchronous generators lessens with amplify of the penetration level of the DG units in the network.

Classic parameters of heat units are used to simulate the two synchronous generators using fifth-order models. IEEE standard regulators are used for simulating the speed governors and the excitation systems. Since the unavoidable power from the generators varies with the variation of the DG power, the rated MVA of the two generators is also changed in each case starting from 110MVA with the 28.3% penetration level up to 150MVA lacking DG units. The reserve power of each generator is assumed to be always 10% of the rated value and, hence, it is in proportional with the nominal power. Consequently, the two generators will pro- vide loftier reserve power when they are used to fully supply the load due to their loftier rating. In each investigated case, the reactive power of each generator is adjusted to obtain the common power factor like that lacking DG units.

CONCLUSION

This study addresses the impact of DG with varied penetration levels on the stability of power systems. A hypothetical network with two conventional power plants and many DG units is simulated. Based on the results and discussion, it can be concluded that DG can improve the stability of power systems if fitting types and appropriate sites are selected. Regarding the oscillatory stability, the utilization of DG improves the damping of the electromechanical modes and slightly amplifies their frequency. This fact is confirmed through the time- domain simulation of some disturbances. The transient stability study shows that the full power-angle deviations among the generators are de- creased with amplify of the penetration level of the DG units. However, the link of some DG units when the voltage lessens lesser than 80% of the nominal value symbolizes wholesale disturbance to the network. With much power from the DG units, the absolute reserve power from synchronous genera- tors and the network inertia constant are minored due to the lesser rated power of the rotating synchronous generators. As a result, the frequency response shows faster behavior with loftier full-frequency deviations when much DG units are employed. The voltage profiles at load terminals are also improved due to the use of active DG sources near end-user terminals. The controllers designed to normalize the permakeedance of the DG units participate also in improving the voltage stability of the network. To maximize the benefits behind utilizing DG units, the stability of the single DG units themselves has to be improved to guarantee their continuous and reliable operation to provide resistive support to the stability of the full network.

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