The Effectiveness of Carbon Nano Tube (Cnt) in Voltage Stability and Power Transfer Capability

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Abstract: Nanotechnology is a popular current research area that has the potential to significantly change the electric utility industry. Carbon nanotubes, which are about the size of a human hair, are long, thin cylinders of carbon that can be single- or multi-walled (cylinders inside the other cylinders). Carbon nanotubes (CNT) have a broad range of electronic, thermal, and structural properties of electric power equipment. Often the economic aspect is pointed out, but also a higher efficiency or a reduction of losses predicts this new technology a successful appearance in power engineering. This paper focuses on increasing stability and maximum loadability of a system by replacing congestion conventional transmission line with proposed carbon nano tube (CNT) line to reduce congestion of the system and /or system losses, hence maximum loading point of the system increase and system dynamic performance improve. The transmission line behavior of a proposed (CNT) is studied. The optimal replacement of congested line based on the use of local marginal price (LMP) differences. The (,) is developed using a standard optimal power flow (OPF) tool. A priority list is formed based on the magnitude of the difference in (LMPs) for the most congested lines. For selected line, it is replaced by proposed (CNT).and using continuation load flow method to find maximum loading point. The effectiveness of the method is tested and illustrated on IEEE 14-bus system. Power System Analysis Toolset (PSAT), a computational tool under Matlab program for effective simulation and monitoring is used.

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1. Introduction:

Power flows in some of the transmission lines are overloaded, which has as an overall effect of deteriorating voltage profiles and decreasing system stability and security. In addition, existing traditional transmission facilities, in most cases, are not designed to handle the control requirements of complex and highly interconnected power systems. This overall situation requires the review of traditional transmission methods and practices, and the creation of new concepts, which would allow the use of existing generation and transmission lines up to their full capabilities without reduction in system stability and security.

Nanotechnology is a popular current research area that has the potential to significantly change the electric utility industry. There were a lot of possible applications to improve electrical, mechanical, thermal or chemical properties of electric power equipment [1]. Carbon-nanotube (CNT) wire product (also called armchair quantum wire for the type of nanotube best suited for the process) has been estimated to have the potential to increase grid capacity by perhaps a million times.

Numerous nanomaterials and other nano-related applications relevant to electricity transmission are in various stages of research, development, and deployment. The application has the potential to directly or indirectly reduce the environmental impact associated with the construction, operation, and dismantlement of electrical transmission technologies. Nanotechnology may help improve the efficiency of electricity transmission wires.

Replacing current wires with nanoscale transmission wires, called quantum wires (QWs) or armchair (QWs), could revolutionize the electrical grid. The electrical conductivity of (QW) is higher than that of copper at one-sixth the weight, and (QW) is twice as strong as steel. A grid Made up of such transmission wires would have no line losses or resistance, because the electrons would be forced lengthwise through the tube and could not escape out at other angles. Grid properties would be resistant to temperature changes and would have minimal or no sag. (Reduced sag would allow towers to be placed farther apart, reducing footprint and attendant construction and maintenance impacts.) Such a grid could have a million times greater capacity than what exists today (assuming the 1-centimeter-diameter aluminum cable carrying about 1,000 to 2,000 amps); even if the capacity were increased by only 0.1%, the amount of enhanced capacity would still be impressive [2]. The realization of such conducting possibilities depends on developing processes for producing high-quality (CNTs) in industrial quantities and at reasonable cost, finding ways to manipulate and orient nanotubes into regular arrays, and developing robust testing methods.

Hjortstam et al [3] a concept for creating a future ultra-low-resistivity material based on a carbon nanotube metal composite was presented. In a simple effective-medium model it was shown that a room temperature resistivity 50% lowers than Cu is achievable. This phenomena is possible because the ballistic conducting carbon nanotubes.

2. Transmission Line Characteristics of a proposed (CNT)

The transmission line behavior of a proposed (CNT) is studied transmission line performance evaluation is carried out, which considers the size and skin effects on its electrical resistivity. The total inductance of the proposed (CNT) coaxial via is dominated by its kinetic Inductance while the total capacitance is determined by its Lower electrostatic capacitance value as indicated By McEuen,et al [4]. In this study, a bundled (CNT)-based coaxial via design is proposed and a RLC transmission line model is developed for it based on the work of Chee and Jianmin [5].

The coaxial transmission line, which consists of an inner conductor and a coaxial outer conducting sheath separated by a dielectric medium, is selected here because it has the advantages of confirming the electric and magnetic fields entirely within the dielectric region and little external interferences are expected to be coupled onto the line. Thus, with a coaxial scheme, the electromagnetic fields that are generated by the (CNT) via, if any, will be enclosed entirely within a grounded shield and any electromagnetic interference between neighboring vias will be kept to very minimal. Finally, the transmission line characteristics of (ACSR) and (SWCNT) are compared.

3. Transmission Line Model

Transmission line model illustrated in Fig.1. Which describe Cross-sectional view of the bundled (CNT) based coaxial an inner conductor (Ød), which is composed of a (CNT) bundle, is surrounded by an outer grounded ($polys_i$) shield (inner ØD).

On either side of the shield, there is a layer of sio_2 insulation. The length (*l*) is limited by the thickness of the Si substrate. A RLC transmission line model is also proposed where Equivalent RLC circuit diagram of the bundled (CNT) coaxial via scheme (long length with the assumption of ideal contacts) as shown in Fig. 2.

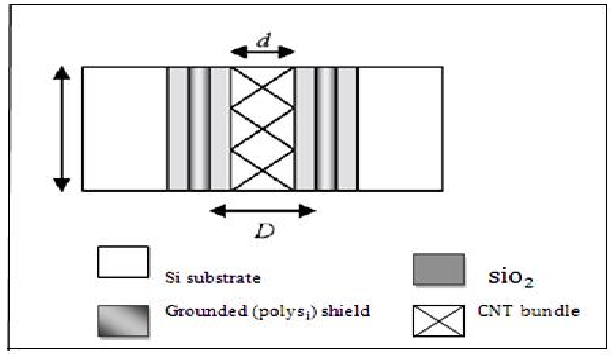

Fig.1. Cross-sectional view of the bundled CNT based coaxial

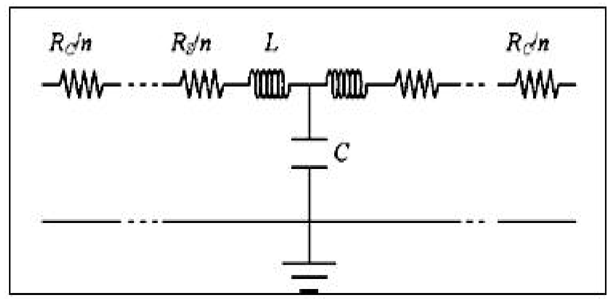

Fig.2. Equivalent RLC circuit diagram of the bundled (CNT) coaxial via scheme (long length with the assumption of ideal contacts)

(CNT) strands do not fill the bundle completely and hence, there are pockets of air spaces between the individual strands. Due to the circular cross-section of (CNTs), even if they are packed efficiently into a hexagonal array, there will still be air spaces in between the places where they touch. Thus, in a bundle, the via is not fully filled by (CNTs) and a fill factor [4] must be introduced, which is approximately 0.9 for a circular method. A growth density factor for (CNTs) is also introduced as it is presently not feasible to achieve a very densely packed CNT bundle. **Nihei *et al.*** [6] managed to grow about 1000 MWCNTs (Ø10 nm) in a 2 μm and this represents a growth density factor of about 0.025. Therefore, the number of (CNTs) in a bundle can be approximately by:

$$n = n_F n_G \left(\frac{d}{d_{cnt}}\right)^2$$

Where n_F is the fill factor, n_G is the growth density factor, and d_{cnt} is the diameter of the (CNT). The following parameters are assumed for the proposed (SWCNT). $n_F = 0.9$, $n_G = 1$, $d_{cnt} = 2\ nm$, the number of (CNTs) in a bundle is $(10^{13}$ CNT) and D/d = 2. The diameter of the (SWCNT) is selected as 2 nm since a densely packed (CNT) bundle of that (SWCNT) diameter has an effective resistivity that is less than that of the bulk cupper. Finally the parameter of proposed bundle (SWCNT) can be calculated according to equations described By McEuen et al & Cheng [4, 7].

4. Continuation Power Flow

The main purpose of Continuation Power Flow is to find the continuity of power flow solution for a given load change .Continuation methods overcome certain difficulties of successive power flow solution methods, as they are not based on a particular system model, and allow the user to trace the complete voltage profile by automatically changing the value of λ; without having to worry about singularities of system equations. The strategy used in Continuation method is shown in Fig.3. [8]. It starts from a known solution and uses a tangent predictor to estimate a subsequent solution corresponding to a different value of the load parameter. This estimate is then corrected using the same Newton-Raphson (NR) technique employed by a conventional power flow. A detailed description of these techniques is referred to Kundur [9].

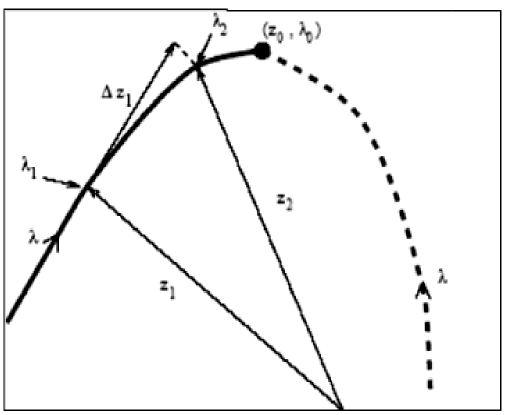

Fig.3. Continuation method

5. DYNAMIC ANALYSIS

Dynamic voltage stability is analyzed by monitoring the Eigen values of the linearized system as a power system is progressively loaded. When the λ parameter varies, the equilibrium points of the dynamic system also vary accordingly, and so do the Eigen values of the corresponding state matrix A_{sys} as shown in Fig.4. Equilibrium points are asymptotically stable if all the Eigen values have negative real parts. The point where a complex conjugate pair of Eigen values reaches the imaginary axis with respect to changes in λ is known as Hopf Bifurcation point. Which is a local bifurcation in which a fixed point of a dynamical system loses stability as a pair of complex conjugate Eigen values of the linearization around the fixed point cross the imaginary axis of the complex plane [10-11] If this particular dynamic problem is studied using gradual changes it can be viewed as Hopf Bifurcation problem. Thus by predicting these types of bifurcations well in advance, a possible dynamic instability problem may be avoided.

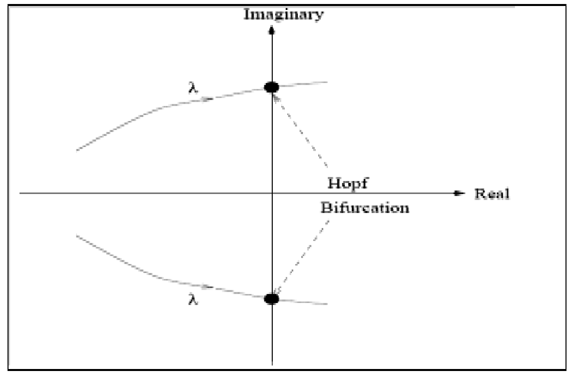

Fig.4. Hopf Bifurcation Point

6. Location marginal price [LMP]

The main concept behind the (LMP) difference method is to make use of the economic signal given as (LMP) to select the congested lines to manage congestion and hence increasing loading stability limit. It is motivated from the fact that (LMP) contains significant information regarding level of congestion in the system [12]. (LMP) is composed of three components, an energy component, a loss component and a congestion component. For a meshed system, loss component is generally small. Hence, the difference in (LMP) between two buses gives direct hint regarding the level of congestion in that line [13].

7. VALIDATIONS STUDIES

7.1 Test system

The IEEE14- bus test system is used for the objective of these studies. Fig.5 depicts the single line diagram of the IEEE 14 bus test system used in this paper. It consists of 14 buses, 20 branches, three transformers, and five synchronous machines. The generators are molded as standard PV buses with both P and Q limits, loads are represented as constant PQ loads.

7.2 Tools

Power system analysis toolbox software (PSAT), which has many features including power flow and continuation power flow [14] .Using continuation power flow feature of PSAT, voltage stability of the test system, is investigated.

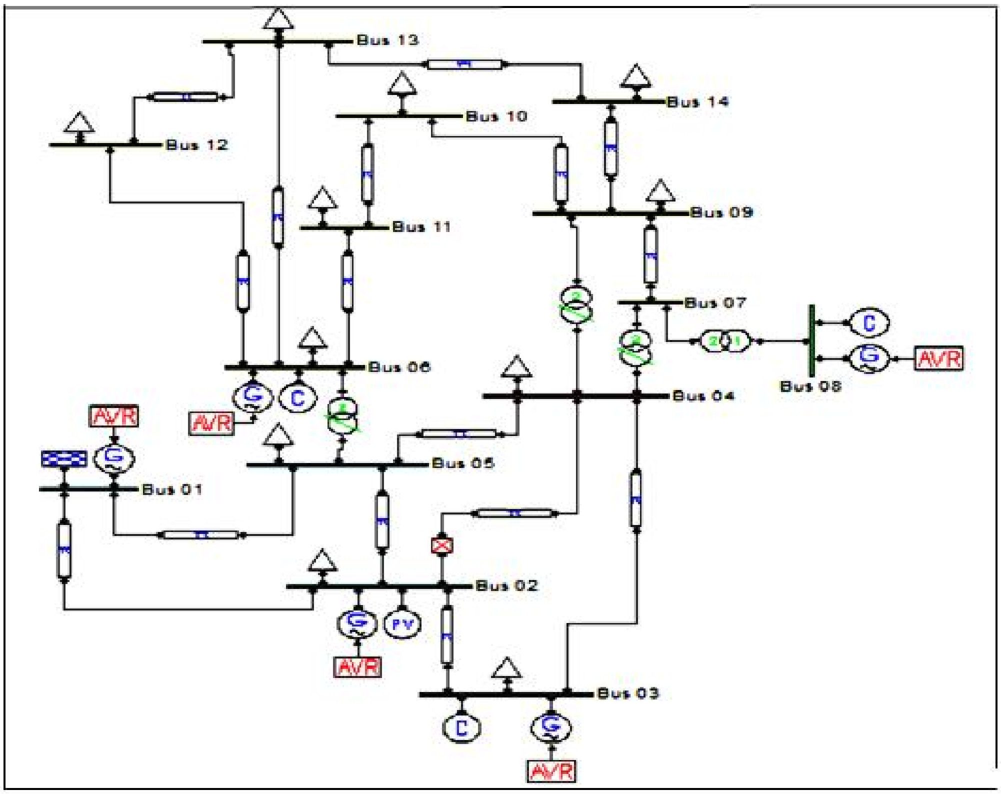

Fig.5. Single line diagram of IEEE 14 bus test

7.3 Simulation Results

7.3.1 Base case

For the Base Case, Single emergency were given in the system and it is observed as the severity of the emergency decreases, the static margin (SM) increases. 1-2 contingency was the most severe case followed by 5-6, 7-9, 3-2 and 1-5 (these being top five) based on (CPF) method. Table 1.and Fig.6 illustrates the dynamic margin (DM) and static margin (SM) associated with P-V curves for the base case, line 7-9 and line 5-6 outages. In these curves, Hopf Bifurcation (HB) points, which were obtained through eigen value analysis, are also depicted.

To study the behavior of the system under large perturbations, a time Domain simulation and eigenvalue computation were performed for a line 5-6 outage at the operating point defined by λ = 1.6 where three phase fault happens at Bus 5 at t =1.s. The fault is cleared at 1.08 s by opening the faulted line. From Fig.7 to Fig.9 show the corresponding time domain simulation results. From these figures, one can conclude that line 5-6 outage leads the system to an oscillatory unstable condition.

Table 1: Dynamic Margins and Static Margins for Base case System

	Normal operating	Line outage 7-9	Line outage 5-6
SM	2.375	1.855	1.726
DM	1.538	1.457	1.347

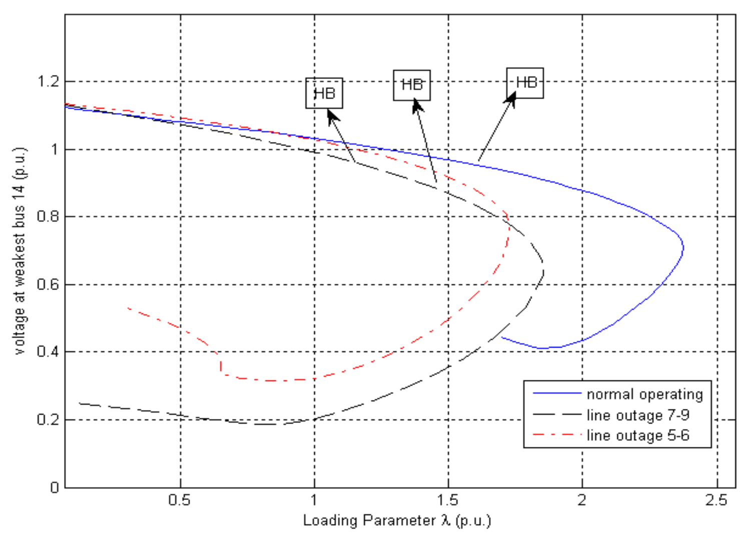

Fig.6. P-V curves at bus# 14 for two emergencies with base case

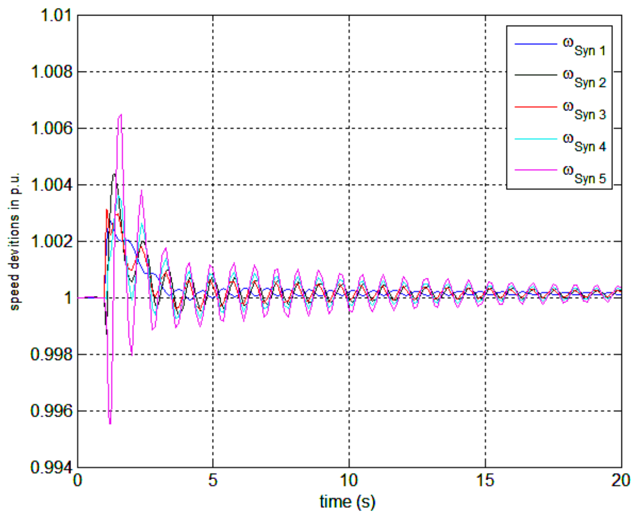

Fig.7. Generator speed oscillation due to line 5-6 outage at λ=1.6 p.u.

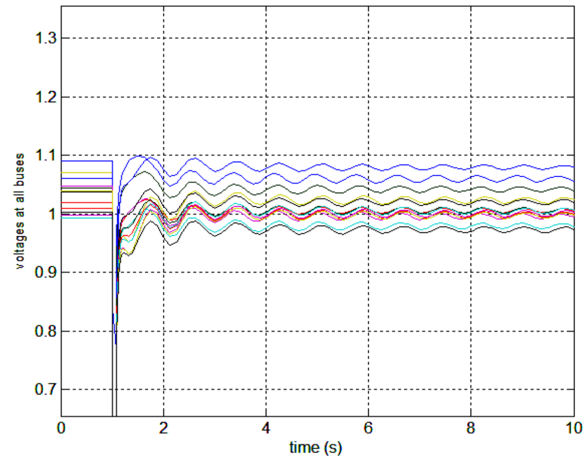

Fig.8. Voltages at all buses due to line 5-6 outage at λ=1.6 p.u.

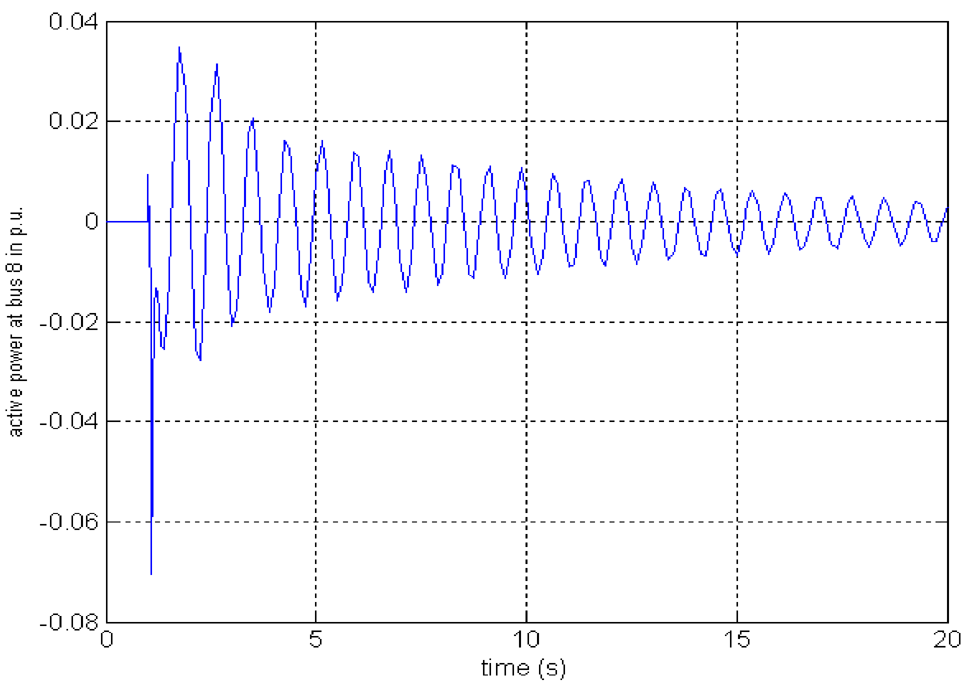

Fig.9. Active power at bus 8 due to line 5-6 outage at λ=1.6 p.u.

7.3.2 Simulation test system with proposed (CNT) line

In this case, the system was simulated with the line made by (CNT). It is already known that the selected line was line 1-5, from congestion line Selection Approach Based on (LMP). Table 2 show the comparison between proposed (CNT) line as discussed above and (ACSR) for electrical properties. The results of replacing the (ACSR) line by the desired (CNT) line are depicted in the Fig.10 for voltage profile at the base case, line 7-9 and line 5-6 outages for maximum loading point. The new maximum loading point in this condition is **λ** = 3.4587 for normal operating with (CNT). Table 3 illustrates the dynamic margin (DM) and static margin (SM) associated with P-V curves shown in Fig.10. It is clear that both (SM) and (DM) have increased in all cases and that the voltage profiles are also improved by replacing (ACSR) line with (CNT) line.

A time Domain simulation was performed for a line 5-6 outage at the operating point defined by λ = 1.6. Thus, Fig.11 to Fig.13 shows the corresponding time domain simulation results. From these figures, one can conclude that for line 5-6 outage with (CNT) instead of the suggested line, this leads to improving for the system to an oscillatory condition.

Table 2: the comparison between proposed (CNT) and (ACSR)

parameter	(CNT) Conductor	(ACSR) Conductor
Resistance (P.U.)	6.72E-3	0.05811
Inductive reactance(P.U.)	3.15E-12	0.17632
Line charging (P.U.)	0.6255	0.0374

Table 3: Dynamic and Static Margins for System with (CNT)

	Normal operating	Line outage 7-9	Line outage 5-6
SM	3.458	2.3	2.04
DM	1.923	1.808	1.64

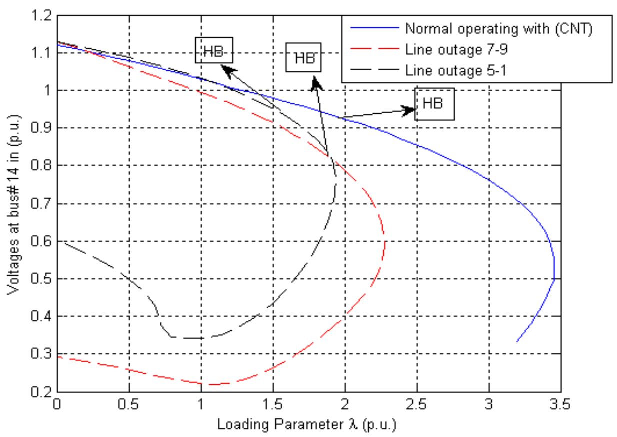

Fig.10: P-V curves at bus# 14 for emergencies and normal operating with (CNT)

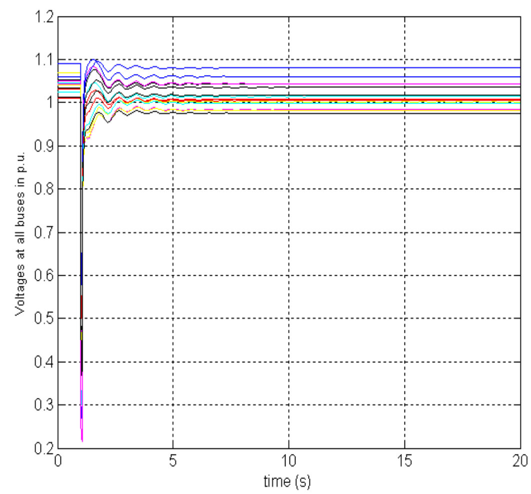

Fig.12: Generator speed oscillation due to line 5-6 outage at λ=1.6 p.u. for system with (CNT)

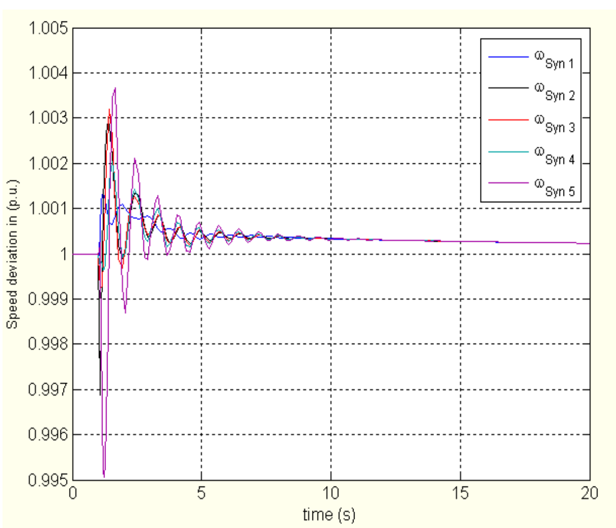

Fig.11: Generator speed oscillation due to line 5-6 outage at λ=1.6 p.u. for system with (CNT)

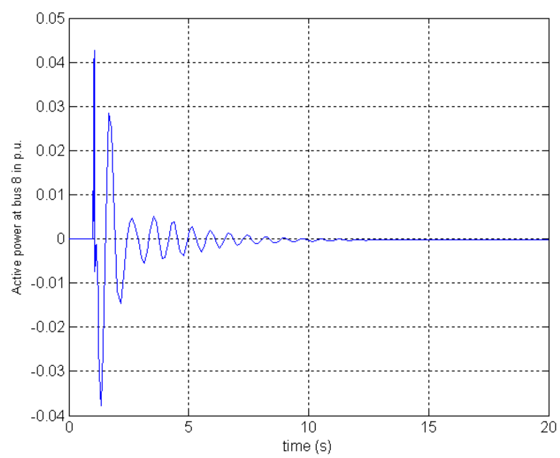

Fig.13: Active power at bus 8 due to line 5-6 outage at λ=1.6 p.u. for system with (CNT)

8. Conclusion

Voltage collapse phenomena and replacing conventional transmission line with new transmission line made by (CNT) are reviewed together with continuation power flow method (CPF). In this paper; the problem of congested line selection for replacing it by proposed (CNT) line has been addressed. In this study, a bundled (CNT)-based coaxial via design is proposed and a RLC transmission line model is developed. The coaxial transmission line, which consists of an inner conductor and a coaxial outer conducting sheath separated by a dielectric medium, is selected. The diameter of the (SWCNT) is selected and hence (CNT) bundle of that (SWCNT) diameter is also determined. The parameter of the proposed T.L is determined for the selected model of T.L. The one line diagram of constructed Simulink with consideration of (CNT) line instead of aluminum conductor steel reinforced (ACSR) line in the test system is introduced. Additionally, the performance of the system with and without (CNT) line is simulated. Based on simulation results obtained in the thesis using continuation load flow method (CPF) can conclude that (CNT) line instead of congested line give higher maximum loadability and minimize the worst case voltage deviations. Also (CNT) line improves system dynamic stability performance through time domain simulation results.

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