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Newton's Method Based Optimal Power Flow Using an Advanced STATCOM

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ABSTRACT: An efficient way of incorporating Static Synchronous Compensator (STATCOM) power flow model into an existing Newton-Based Optimal Power Flow (OPF) algorithm is presented in this paper. This model introduces the magnitude and angle of the source converter's voltage as a state variable into the OPF problem formulation. Unlike previous works, where the value for the reactive support required by the STATCOM is specified at the beginning of the solution process, this work considers this value to be an optimal one by representing the source converter of the STATCOM as a generator bus. An existing computer program was modified to accommodate this upgrade. The modified program was applied to a 5-bus test system and the results obtained were compared with the results for an SVC-upgraded OPF algorithm available in open literature The results obtained are presented and discussed.

KEYWORDS: FACTS, Newton's method, optimal power flows, STATCOM, voltage source converter.

I. INTRODUCTION

In electric power systems, high voltage transmission lines are always categorised as either medium or long. These categories of lines usually have significant shunt capacitances. If the receiving bus of such a line is lightly loaded, it may experience high voltage magnitude. On the other hand, if the receiving bus of a high voltage transmission line is heavily loaded, it may result to a low voltage magnitude on such bus. Both low and high voltage magnitude can trigger protective devices which can interrupt electric supply to the consumers. Regulating voltage magnitude in the network requires the regulation of reactive power flow. Examples of devices that are used for such purpose are shunt reactors, shunt capacitors, SVC's and STATCOM's. Shunt reactors are designed to regulate high voltage magnitude while shunt capacitors are designed for low voltage magnitude. Unlike these two devices, the SVC's and STATCOM's can conveniently and flexibly perform the functions of these two devices depending on the operating condition of the network. In principle, the STATCOM does the same voltage regulation as the SVC but in a more robust manner. Previous works had explained the incorporation of SVC models into a Newton-Raphson load flow and OPF algorithm. The incorporation of STATCOM into an existing Newton-based power flow algorithm
had also been addressed in the past.
The power flow model developed was used in
this work to present an efficient procedure involved in the incorporation of STATCOM into an existing Newton-based OPF MATLAB program where generator fuel cost functions were optimized while maintaining a satisfactory power system constraints. The reactive power flow equation of the source converter of the STATCOM was treated in the OPF algorithm

the same way as the equation for a generator
bus. It is worthy of notice that the value for reactive power required by the STATCOM is usually specified at the beginning of the solution procedure. Using this same approach for OPF may not yield an optimal solution An existing OPF program [6] was modified to accommodate the STATCOM models. Optimal solutions of the new STATCOM model yield considerable reductions in power system losses and in the converter's internal power losses, when compared to the solutions furnished by the STATCOM model solved using conventional
power flows. Furthermore, optimal solutions with the new STATCOM model will also yield improved solutions compared to the optimal solutions provided by the voltage source representation of the STATCOM, and with less computational complexity.

II. LITERATURE REVIEW AND RELATED WORKS

1) E. Acha and B. Kazemtabrizi, The paper presents a new model of the STATCOM aimed at power flow solutions using the Newton-Raphson method. The STATCOM is made up of the series connection of a voltage-source converter (VSC) and its connecting transformer. The VSC is represented in this paper by a complex tap-changing transformer whose primary and secondary windings correspond, notionally speaking, to the VSC's ac and dc buses, respectively. The magnitude and phase angle of the complex tap changer are said to be the amplitude modulation index and the phase shift that would exist in a PWM inverter to enable either reactive power generation or absorption purely by electronic processing of the voltage and current waveforms within the VSC. The new STATCOM model allows for a comprehensive representation of its ac and dc circuits-this is in contrast to current practice where the STATCOM is represented by an equivalent variable voltage source, which is not amenable to a proper representation of the STATCOM's dc circuit. One key characteristic of the new VSC model is that no special provisions within a conventional ac power flow solution algorithm is required to represent the dc circuit, since the complex tap-changing transformer of the VSC gives rise to the customary ac circuit and a notional dc circuit. The latter includes the dc capacitor, which in steady-state draws no current, and a current-dependent conductance to represent switching losses. The ensuing STATCOM model possesses unparalleled control capabilities in the operational parameters of both the ac and dc sides of the converter. The prowess of the new STATCOM power flow model is demonstrated by numerical examples where the quadratic convergence characteristics of the Newton-Raphson method are preserved.

2) X. Zhang and E. J. Handshcin,
In this paper, general mathematical models for power converter-based FACTS controllers such as STATCOM, SSSC and UPFC suitable for optimal power flow study are established. There are several solution methods for OPF available, which include interior point methods. In this paper, the optimal power flow problem with these converter based FACTS controllers is solved by the newly developed nonlinear interior point methods, since they have been the most successful OPF methods.

3) M. Hagiwara and H. Akagi, A modular multilevel converter (MMC) is one of the next-generation multilevel PWM converters intended for high- or medium-voltage power conversion without transformers. The MMC consists of cascade connection of multiple bidirectional PWM chopper-cells and floating do capacitors per leg, thus requiring voltage-balancing control of their chopper-cells. However, no paper has been discussed explicitly on voltage-balancing control with theoretical and experimental verifications. This paper deals with two types of modular multilevel PWM converters with focus on their circuit configurations and voltage-balancing control. Combination of averaging and balancing controls enables the MMCs to achieve voltage balancing without any external circuit. The viability of the MMCs as well as the effectiveness of the PWM control method is confirmed by simulation and experiment.

4) A. Santos, Jr and G. R. M. d. Costa, The paper describes a new approach to the optimal-power-flow problem based on Newton's method which it operates with an augmented Lagrangian function associated with the original problem. The

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function aggregates all the equality and inequality constraints. The first-order necessary conditions for optimality are reached by Newton's method, and by updating the dual variables and the penalty terms associated with the inequality constraints. The proposed approach does not have to identify the set of binding constraints and can be utilised for an infeasible starting point. The sparsity of the Hessian matrix of the augmented Lagrangian is completely exploited in the computational implementation. Tests results are presented to show the good performance of this approach.

III. EXISTING SYSTEM

In radial interconnected distributed system, voltage is not distributed equally to all the parts of entire system. Due to load changes on every time to time, normally loads are inductive or capacitive loads. Since reactive power are injected in to the system so the system needs compensation for to reduce reactive power. In olden days capacitor banks are utilized at the received end in distribution system. Now a day's static compensators are used i.e., D-STATCOM, UPQC etc. But in inter connection system very difficult to place a compensator at a particular place because of system loads. Real-time applications such as optimization of network, switching, estimation of the state, and so on, requires an efficient and standard power flow technique. Due to special features of distribution systems such as Radial structure, high ratio of R/X and wide-ranging reactance and resistance values. To optimize the inter connected system some techniques are used to find the minimum nodal voltage point.

IV. PROPOSED TECHNIQUE

The three-node system with the STATCOM modeled as a controllable voltage source is shown in Fig. 1. The OPF solution converges in 3 global iterations. These results are compared to those produced by the new STATCOM model. The STATCOM controllable voltage source model generates 0.6110 p.u. of reactive power to maintain the voltage at node 2 at 1.02 p.u. The converter voltage stands at 1.0510 p.u. The converter voltages behind the converter impedance for both models are compared. The powers calculated by both models are presented. he switching losses in this test case are modeled by connecting a shunt conductance of 1% between the coupling impedance and the variable voltage source. In fact, this shunt resistive branch should be connected at the DC bus of the VSC as opposed to its AC side but is precluded because the voltage source converter model does not have such a bus and the results concerning switching losses willbe inaccurate and optimistic.

By comparing the results given by the OPF solution of the three-node radial system with the STATCOM modeled using the new model and a controllable voltage source model respectively, the following limitations are clearly observed: 1) lack of explicit DC bus representation which means that the converter voltage is represented by only one state variable pertaining to the controllable voltage source. Therefore there is no direct means of controlling the AC output voltage of the converter by varying the DC input voltage. 2) In the controllable voltage source model there is no way of limiting the operation of the PWM modulation coefficient within the linear region, therefore the results obtained from a controllable voltage source model do not provide sufficient information to distinguish the regions of operation of the converter. This may be done by only introducing a new explicit state variable in the OPF formulation, further complicating the overall formulation of the problem, whereas, with the new model, this is already included in form of the complex tap ratio of the transformer modeling the PWM-control of the VSC.

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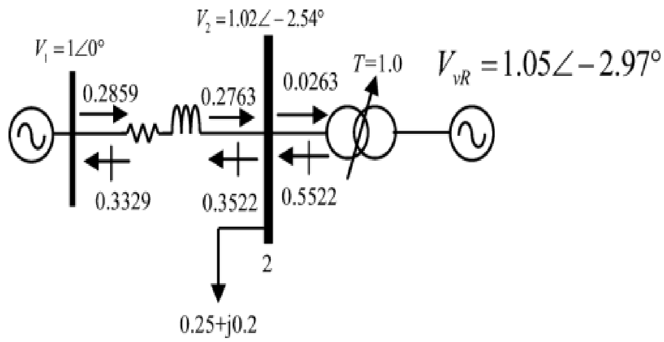


Fig.1.Fictitious three-node radial system STATCOM controllable voltage source model representation.

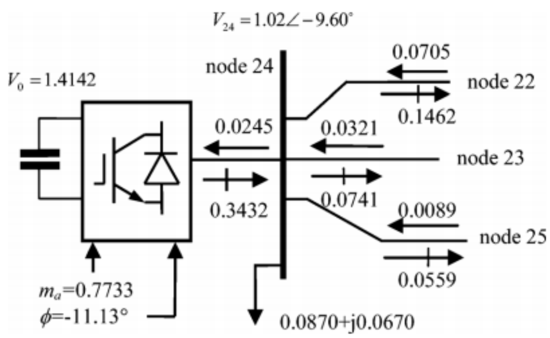
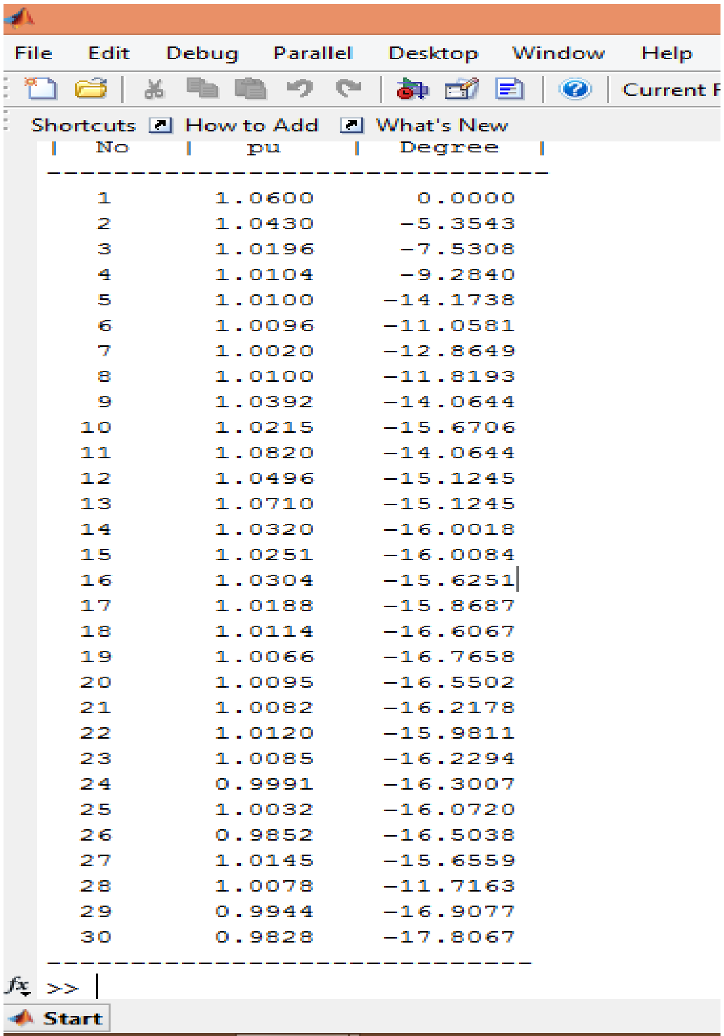


Fig. 2. STATCOM supplying reactive power at node 24 of the modified IEEE 30-node system to regulate voltage magnitude at 1.02 p.u.

In order to test the performance of the new STATCOM model in a larger network, the IEEE 30-node system is selected. The fixed bank of capacitors at node 24 is replaced with a STATCOM, which is used to regulate voltage magnitude at that node at 1.02 p.u. The modified portion of the 30-node system is shown in Fig. 4. The nodal voltage magnitudes are allowed to vary between 0.9 and 1.1 p.u. at all 24 load buses and between 0.9 and 1.05 p.u. at all six generator buses. Node 1 is taken to be the slack bus. The Newton's OPF arrives to the solution in eight global iterations. The slow convergence rate is the result of enforcing inequality constraints in voltage magnitudes for violated
nodes. The STATCOM consumes 0.0245 p.u. of
active power of which 0.81% is for VSC internal switching losses, whilst 1.64% accounts for OLTC Ohmic losses. The STATCOM generates 0.3432 p.u. of reactive power to maintain the voltage magnitude at node 24 to 1.02 p.u. The OLTC final tap is rounded off to 0.7. Notice that the powers shown are the output powers at the OLTC transformer terminals as opposed to the VSC terminals.

V. SIMULATION RESULTS



No	pu	Degree
1	1.0600	0.0000
2	1.0430	-5.3543
3	1.0196	-7.5308
4	1.0104	-9.2840
5	1.0100	-14.1738
6	1.0096	-11.0581
7	1.0020	-12.8649
8	1.0100	-11.8193
9	1.0392	-14.0644
10	1.0215	-15.6706
11	1.0820	-14.0644
12	1.0496	-15.1245
13	1.0710	-15.1245
14	1.0320	-16.0018
15	1.0251	-16.0084
16	1.0304	-15.6251
17	1.0188	-15.8687
18	1.0114	-16.6067
19	1.0066	-16.7658
20	1.0095	-16.5502
21	1.0082	-16.2178
22	1.0120	-15.9811
23	1.0085	-16.2294
24	0.9991	-16.3007
25	1.0032	-16.0720
26	0.9852	-16.5038
27	1.0145	-15.6559
28	1.0078	-11.7163
29	0.9944	-16.9077
30	0.9828	-17.8067

Fig.3. simulation data

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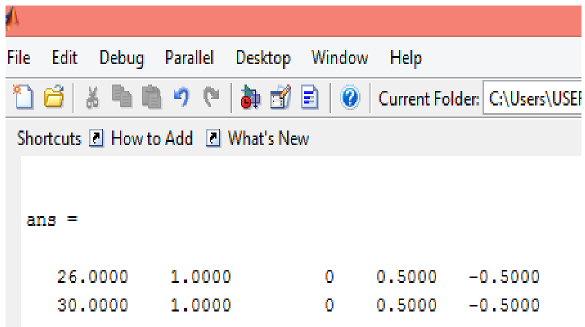
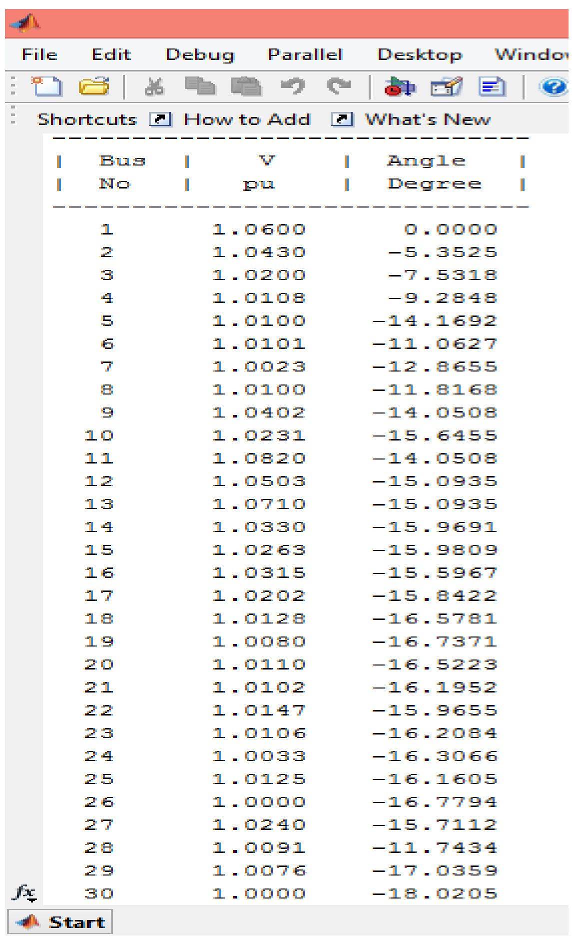



```
ans =

   26.0000    1.0000         0    0.5000   -0.5000
   30.0000    1.0000         0    0.5000   -0.5000
```

Fig.4. simulation result



Bus No	V pu	Angle Degree
1	1.0600	0.0000
2	1.0430	-5.3525
3	1.0200	-7.5318
4	1.0108	-9.2848
5	1.0100	-14.1692
6	1.0101	-11.0627
7	1.0023	-12.8655
8	1.0100	-11.8168
9	1.0402	-14.0508
10	1.0231	-15.6455
11	1.0820	-14.0508
12	1.0503	-15.0935
13	1.0710	-15.0935
14	1.0330	-15.9691
15	1.0263	-15.9809
16	1.0315	-15.5967
17	1.0202	-15.8422
18	1.0128	-16.5781
19	1.0080	-16.7371
20	1.0110	-16.5223
21	1.0102	-16.1952
22	1.0147	-15.9655
23	1.0106	-16.2084
24	1.0033	-16.3066
25	1.0125	-16.1605
26	1.0000	-16.7794
27	1.0240	-15.7112
28	1.0091	-11.7434
29	1.0076	-17.0359
30	1.0000	-18.0205

Fig.5.1 simulation output of stat out

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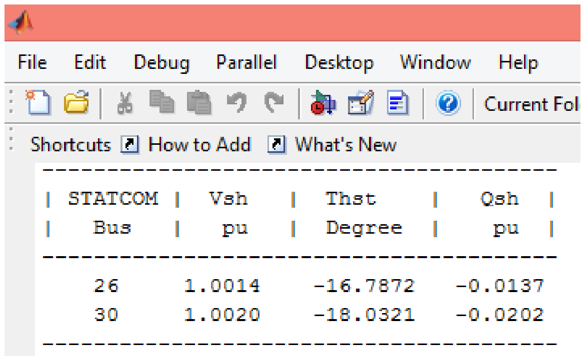

STATCOM Bus	Vsh pu	Thst Degree	Qsh pu
26	1.0014	-16.7872	-0.0137
30	1.0020	-18.0321	-0.0202

Fig.5.2 simulation output of statcom out

VI. CONCLUSION

A new STATCOM model using Newton's method is presented in this paper for optimal power flow solutions. The new model separate from the idealized controllable voltage source concept that has been used so far for representing the fundamental frequency operation of the STATCOM in OPF formulations. It treats the DC-to-AC converter of the STATCOM as a transformer device with a variable complex
tap like step up and step down Transformers. The PWM control of the VSC is modeled explicitly by means of the complex tap of the ideal transformer whose magnitude represents the PWM amplitude modulation coefficient and its phase angle corresponds to the phase shift that would exist between the fundamental frequency voltage and current wave forms. Moreover, the phase angle of the complex tap in the new VSC model coincides with the phase angle of the conventional, equivalent voltage source model of the VSC. The STATCOM-OPF model is tested in a radial system configuration to showcase the regulating properties of the new model. A larger system comprising several generators has been selected to show that the new STATCOM model performs equally well
within Newton's OPF solution.

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