Impact of distribution network reconfiguration under wheeling transactions

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ABSTRACT. Under deregulated environment, reconfiguration of distribution network is a complex process. Distribution System Operator (DSO) reconfigure network for various reasons such as loss minimization, voltage profile betterment etc. In complex, large scale distribution network reconfiguration may produce desirable or undesirable results for wheeling transactions. Therefore, this paper focuses on the analysis of impact of Distribution Network Reconfiguration (DNR) under wheeling transaction, incorporating market dispatching considerations. Further, the mathematical model of Wheeling transactions takes into account of the additional losses occurred during wheeling transaction. The proposed problem is mitigated using a new optimization algorithm – Differential Search Algorithm (DSA). DSA has a simple structure that is effective, fast and capable of solving multimodal problems and that enables it to easily adapt to different numerical optimization problems. The proposed methodology has been tested on IEEE 33-bus distribution system. Simulation results are presented with relevant analyses and discussions.

RÉSUMÉ. Dans un environnement déréglementé, la reconfiguration du réseau de distribution est un processus complexe. L'opérateur de système de distribution (DSO) reconfigure le réseau pour diverses raisons telles que la réduction des pertes, l'amélioration de la distribution de la tension, etc. Dans les réseaux de distribution complexes à grande échelle, la reconfiguration peut produire des résultats souhaitables ou indésirables pour des transactions en transit. Par conséquent, le présent document se concentre sur l' analyse de l'impact de la reconfiguration du réseau de distribution (DNR) dans le cadre d'une transaction en transit, intégrant des considérations relatives à la répartition du marché. En outre, le modèle mathématique des transactions en transit prend en compte les pertes supplémentaires survenues lors de la transaction en transit. Le problème proposé est atténué à l'aide d'un nouvel algorithme d'optimisation, l'algorithme de recherche différentielle (DSA). Le DSA a une structure simple, efficace, rapide et capable de résoudre des problèmes multimodaux et qui lui permet de s'adapter facilement à différents problèmes d'optimisation numérique. La méthodologie proposée a été testée sur un système de distribution par bus IEEE 33. Les résultats de la simulation sont présentés avec des analyses et des discussions pertinentes.

KEYWORDS: *distribution systems, differential search algorithm, network reconfiguration, wheeling transactions.*

MOTS-CLÉS: *systèmes de distribution, algorithme de recherche différentielle, reconfiguration du réseau, transactions en transit.*

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1. Introduction

The DSO (Distribution System Operator) plays an important role in ensuring national energy security. DSO handles electricity distribution and is responsible for network traffic in the distribution system. In the present day deregulation environment grant of Distribution Open Access (DOA) to consumers sourcing power from Distributed Generation (DG) such as Wind, Solar, and Small Hydro makes the problem for the Distribution System Operator (DSO) more and more complex. The terminology "Wheeling" in deregulated power industry refers to "The use of transmission or distribution facilities of a system to transmit power of and for another entity or utilities" as described by Hyde *et.al*. (1989). Wheeling, in general is the transmission of power from a seller to a buyer through the network owned by a third party as in Caramins *et al*. (1986).

Many literatures as in Sood. *et al*. (2002) on Electricity Deregulatory act are available on incorporating wheeling transactions in DOA system. A detailed survey on Wheeling transaction is given in Maharashtra state electricity distribution (2013). From the Delhi Electricity Regulatory Commission, (2013) and B. Venkatesh *et al*. (2004), it is understood that wheeling transactions on the basis of either bilateral or multilateral trades in Distribution Open Access (DOA) incorporates the following financial aspects

- Wheeling Charges / Transmission Charges, as may be applicable;
- Wheeling Losses & Transmission losses, as may be applicable;
- Cross Subsidy Surcharge, as may be applicable;
- Additional Surcharge on the Charges of Wheeling;
- Standby Charges;

If an DG at bus 'i' is willing to supply a load at bus 'j' then for this wheeling transaction WT(i-j), the DSO should determine the maximum allowable load at bus 'j' considering non-violation of system constraints and for better economic aspects. The maximum power that can be wheeled in the network at a given time depends on the distribution network, subject to satisfying the constraints occurring in Distribution Utility, DG, and distribution sectors along with the maximum cost benefits. There are many literatures available on wheeling transactions in distribution network but, impact of Distribution Network Reconfiguration (DNR) under wheeling is not much studied. DNR in distribution systems is realized by changing the status of sectionalizing switches, for improving network performance. This involves the use of either deterministic or stochastic optimization algorithms. Extensive research work by Chang (2008), Rayapudi *et al*. (2011), Subas *et al*. (2014), Savier *et al*. (2007), Mesut *et al*. (1989) and H.Kazemi Karegar et.al. (2008) are carried out on the application of DNR for loss minimization, loss allocation, load balancing and Energy cost minimization etc. Further, Gautam *et al*. (2007), kotamarty *et al*. (2008), Antonio Piccolo *et al.* (2009), Seyed *et al*., (2014) and Wu *et al*. (2010) gives DGs sizing and placements studies which are carried out with and without DNR techniques for loss minimization and or voltage profile improvement. DNR technique under congestion management is studied by Shariatkhah *et al*., (2012) and Afkousi *et al*. (2010).

From the above mentioned literatures it is understood that the DNR and optimal sizing and placement of DGs are extensively used for many power distribution network problems but fails to investigate wheeling transactions under deregulation. Hence this paper focuses on the impact of DNR in wheeling transactions under deregulated environment. To investigate the impact of DNR a new optimization algorithm - Differential Search Algorithm (DSA) is proposed. The Differential Search Algorithm (DSA) is a population based meta-heuristic optimization algorithm developed by Civicioglu 2012. DSA has a simple structure that enables it to easily adapt to different numerical optimization problems. For the problems of highly nonlinear and multi modal nature, it has been proved that DSA works well when compared to various recent optimization algorithms developed by Civicioglu 2012.

The remaining of the paper is organized as follows: Section 2 deals with mathematical formulation of DNR under wheeling transactions. Section 3 presents a brief procedure of DSA algorithm and its implementation for the proposed problem is explained in Section 4. Simulation results for DNR under wheeling transactions on IEEE 33 bus radial distribution system is presented in Section 5 and Section 6 draws the conclusions.

2. Mathematical formulation of DNR under wheeling transactions

If an DG at bus ‘i’ is willing to supply a load at bus ‘j’ then for this wheeling transaction W_T(i-j), the DSO can reconfigure the network in such a way that the overall losses are minimum when compared to the case without reconfiguration under wheeling transactions.

Therefore three case studies are formulated

Case 1: *DNR of Base case network (without wheeling transaction) for loss minimization*

Case 2: *With Case 1 optimal network, perform wheeling transaction and calculate losses. The additional loss (if any) occurred when compared to Case 1, should be supplied by the seller*.

Case 3: *DNR of Base case network (with wheeling transaction) for loss minimization*.

Hence, in all three cases the objective function to be minimized is the distribution loss present in the network. It can be mathematically given as below

$$\min(PLOSS) = \min\left(real\left[\sum_{k=1}^{NL}(S_{k,ij} + S_{k,ji})\right]\right) \quad (1)$$

Subject to

$$PGi - PDi - \sum_{j=1}^{n} PLOSSij = 0 \quad (2)$$

$$QGi - QDi - \sum_{j=1}^{n} QLOSSij = 0 \quad (3)$$

$$Vmin, i \le Vi \le Vmax, i \quad (4)$$

$$PGi \le PGmax, i \quad (5)$$

Where, PGi is the real power generation at bus *'i'*

PDi is the real load in bus 'i'

$PLOSSij$ is the active power loss in the line *ij*

QGi is the reactive power generation at bus 'i'

QDi is the reactive load in bus 'i'

$QLOSSij$ is the reactive power loss in the line *ij*

Vi is the voltage at bus 'i'

$Vmin, i$ is the minimum and maximum voltage limits at bus 'i'

$Vmax, i$ is the maximum voltage limits at bus 'i'

Sij is the apparent power flow in the line *ij*

$S_{k,ij}$ is the complex power flowing from bus 'i' to 'j'

$S_{k,ji}$ is the complex power flowing from bus 'j' to 'i'

$PGmax, i$ is the maximum real power generation available at bus 'i'

NG is the total number of generators

NL is the total number of transmission lines

3. Differential search algorithm

The Differential Search Algorithm (DSA) is a population based meta-heuristic optimization algorithm which simulates the *Brownian-like random-walk* movement used by an organism to migrate from one place to another based on climatic changes. During these climatic changes these organisms migrate from an environment where the available sources of nature are limited, to an environment which is rich in sources.

In the migration movement, the migrating species of living beings constitute a *superorganism* containing a large number of individuals. Then it starts to change its position by moving towards more fruitful areas using a *Brownian-like random-walk* model. The population made up of random solutions of the respective problem corresponds to an artificial *superorganism* migrating. The artificial *superorganism* migrates to a near global minimum value of the problem. During this migration, the artificial *superorganism* tests whether some randomly selected positions are suitable temporarily during the migration. If such a position tested is suitable to stopover for a temporary time during the migration, the members of the artificial super organism that made such discovery immediately settle at the discovered position and continue their migration from this position on. Detailed explanation and pseudo-code of DSA can be found in the work of Civicioglu 2012.

4. DSA for DNR under wheeling transactions

In the problem of DNR the loss minimization is obtained by optimally selecting switches which are to be closed and opened. When a tie switch is closed a loop is formed, therefore another switch in that loop should be opened to ensure radial structure. For this reason first, a *Switch_Information_Matrix* (SIM) is formulated which contains the information of the sectionalizing and or tie switches to be opened when a corresponding tie switch is closed. This depends on the number of loops created. The row size of SIM depends upon the number of tie switches whereas the size of column depends on the number of switches present in that loop. Hence the DSA should select a suitable switch number from the SIM matrix. A description about the implementation of DSA for DNR problem is given below.

4.1. Implementation of DSA for DNR under wheeling transactions

The problem is initialized as given below

$$X_{min} = [111\ldots\ldots 1 \quad] \tag{6}$$

$$X_{max} = [Lm1\ \ Lm2\ \ Lm3\ldots\ldots LmD] \tag{7}$$

where ‘Lm’ refers to the maximum number of lines in each loop, ‘D’ is the dimension vector or number of tie switches and ‘X’ is the artificial organism. Assuming a total population of ‘NP’, then we may initialize the j^{th} component of i^{th} vector (assuming i = 1, 2, 3,…..NP) as

$$x_{ij} = rand\ (X_{max} - X_{min}) + X_{min} \quad j = 1, 2, 3, \ldots..D \tag{8}$$

thus forming the artificial organism

$$X_i = [x_{i1}, x_{i2}, x_{i3}, \ldots.. x_{iD}] \tag{9}$$

Each artificial organism corresponds to chromosomes of Genetic Algorithm (GA), on the other hand the population set of GA refers to Super organisms i.e. $Superorganism_g = [X_i]_g$ where $g = 1,\dots$, NG (number of maximum generations). Randomly, the $Superorganism_g$ is shuffled to form *donors* in order to discover the *stopover site.* A *stopover site* (vectors- Xs_i) at the areas remaining between the artificial organisms using a *Brownian-like random walk* model are determined using

$$Stopoversite_g = Superorganism_g + Scale \times (donor - Superorganism_g) \quad (10)$$

The Scale value is produced using a gamma-random number generator which allows the respective artificial *Superorganism* to radically change its direction in the habitat. Then using a random search process as given by P. Civicioglu 2012 an update in *Stopoversite* is made.

The selection of new artificial $Superorganism_{g+1}$ is chosen between the existing *Stopoversite* and the $Superorganism_g$ as given below

$$[X_i]_{g+1} = [Xs_i]_g \quad \text{if} \quad f([Xs_i]_g) \leq f([X_i]_g) \quad (11)$$

$$= [X_i]_g \quad \text{if} \quad f([Xs_i]_g) \geq f([X_i]_g)$$

4.2. Algorithm of DNR for wheeling transaction using DSA

The step by step algorithm DNR for wheeling transaction using DSA is as given below

Step 1: Read feeder data, line data, wheeling transaction – seller bus (DG sizing) and buyer bus (load demand), size of population, number of tie switches etc.

Step 2: **For Case 1:**
The DSA algorithm (sec.4.1) is used to find the optimal reconfigured network with minimum loss for base case.

Step 3: **For Case 2:**
Establish the wheeling transaction in the optimal network of Case 1. i.e. connect the generator at seller bus and increase the load at buyer bus while keeping the feeder generations at optimal values obtained in Case 1. Run power flow and find the loss occurred in optimal reconfigured network of Case 1 under wheeling transactions.

Step 4: **For Case 3:**

Establish the wheeling transaction in the Base case network i.e. to connect the generator at seller bus and increase the load at buyer bus. Use DSA algorithm to find the optimal reconfigured network while minimizing the losses.

Step 5: Compare the results of Case 2 and Case 3 for minimum loss which gives the impact of DNR under wheeling transactions.

5. Simulation results and discussion

The test system chosen for studying the impact of DNR under wheeling transaction is IEEE 33 bus radial system cited by Mesut *et.al.* (1989). The complete DSA coding and power flow using MATPOWER used by R. D. Zimmermann *et.al.* (2007) is done in MATLAB 2009b environment using INTEL core 2 Duo CPU T5500@ 1.66 GHz processor, 2 GB RAM under Windows XP professional operating system. The parameters for DSA are Number of population -30, Number of Generations – 300, trial pattern generation P = 0.3 * random number. The simulation results for each case is as given below

5.1. Case 1

IEEE 33 bus radial network has 32 sectional lines with 5 tie switches. Its total complex power demand is 3.72 + j 2.3 MVA. Also, for the base case network (without DNR) the power loss is 202.7052 kW. After applying DNR using DSA method the optimal network and its losses are as furnished in Table 1.

Table 1. Comparison of simulation results without DNR and with DNR using DSA

Method	**Without DNR**		**With DNR**	
	Lines switched out	**Total Loss (kW)**	**Lines switched out**	**Total Loss (kW)**
Rayapudi *et.al.*(2011)	33-34-35-36-37	202.705	7-10-14-36-37	142.68
Y.K.Wu *et.al.* (2010)	33-34-35-36-37	202.705	7-9-14-28-32	139.98
Khodar HM *et.al.* (2009) and De Macedo et.al. (2011)	33-34-35-36-37	202.705	7-9-14-32-37	139.55
DSA (proposed)	**33-34-35-36-37**	**202.705**	**7-9-14-32-37**	**139.56**

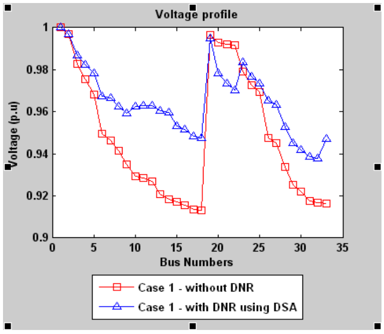
It can be observed that configuration obtained by the proposed method is one of the best solutions obtained so far. The percentage reduction in power loss is 31.1465%. The minimum voltage is 0.9138 p.u. at bus 18 without DNR, whereas the minimum voltage with DNR using DSA is 0.9378 p.u. at bus 32. The voltage profile at all buses without DNR and with DNR using DSA is shown in Fig 1. The convergence characteristics are shown in Fig 2.

5.2. Case 2

The data for generator and load for wheeling transactions are as given in Table 2.

Table 2. Data for Wheeling transaction (Bilateral)

Generator (Seller)	Bus 16	Pg = 100 kW	Pgmax= 500 kW Pgmin = 0 kW	Qg = 0 kVar i.e pf = unity
Load (Buyer)	Bus26 (additional load)	Pd = 100 kW	Qd = 0 kVar	



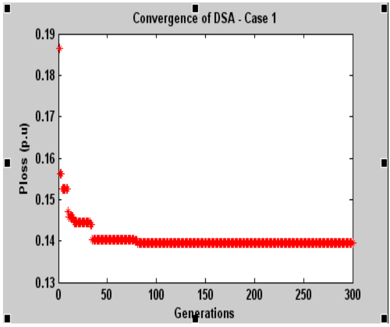


Figure 1. Case 1 - Voltage profile   *Figure 2. Case 1 - Convergence of DSA*

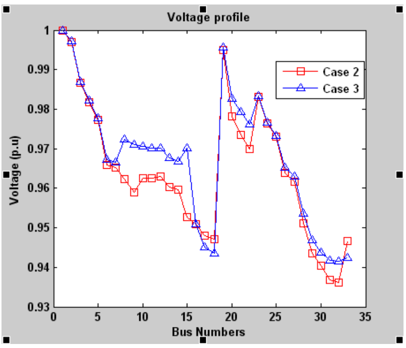
For case 2, the above mentioned wheeling transaction is established in the optimal network obtained in Case 1, i.e with lines 7-9-14-32-37 switched out. The observations based on load flow are furnished in column 2 of Table 3. It is observed that the additional load of 100 kW at the buyer bus 26, increases the losses from the optimal case 1 value of 139.56 kW to 142.67kW. Hence this additional loss 3.11kW loss has to be supplied by the seller. Hence the establishment of wheeling transactions in case 1 optimal network is not economically worthy either for the seller or for the distribution utility.

Table 3. Simulation results for Case 2 and Case 3 - Wheeling transaction (Bilateral)

Wheeling transactions	**Case 2**	**Case 3**
Lines switched out	7-9-14-32-37	**7-10-14-15-37**
Minimum Voltage	0.9362	**0.9415**
Total loss	142.67 kW	**122.85kW**
% Reduction in loss	-	**13.89 %**

5.3. Case 3

For case 3, the Table 2 data for wheeling transaction is established and the DNR using DSA is applied again as in Case1. The Voltage profiles of case 2 and case 3 is shown in Fig 3. And the convergence characteristics for DNR using DSA are shown in Fig 4. The optimal network and the corresponding losses are furnished in column 3 of Table 3. For this case the total loss is 122.85kW which is 13.89 % lesser when compared to Case 2. Further, the voltage profile is also improved when compared to Case 2. Hence the Distribution utility (DSO) has to participate in the wheeling transaction by optimally reconfiguring the network so that the utility, seller and the buyer can benefit economically.



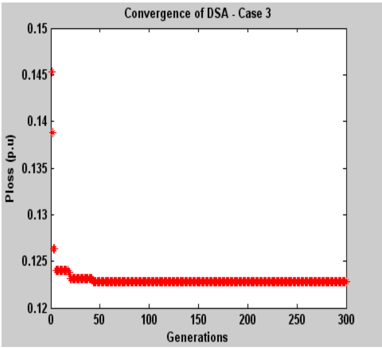


Figure 3. Case 2 & Case 3-Voltage profile *Figure 4. Case 3–Convergence of DSA*

6. Conclusions

This paper presented the analysis of impact of Distribution Network Reconfiguration (DNR) under wheeling transaction, incorporating market dispatching considerations. Three different case studies: Case 1, Case 2 and Case 3 are considered. All these cases are tested on IEEE 33-bus distribution system using a new optimization algorithm DSA. DSA has a simple structure that is effective, fast and capable of solving DNR problems under wheeling transactions. From the simulation results it can be concluded that under wheeling transactions applying DNR method (Case 3) is more beneficial for distribution utility, seller and the buyer when compared to Case 2.

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