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Cost and Stability Analysis of Microgrids in Presence Of Evs Based On Dynamic Modeling

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ABSTRACT
Development of Electrical Vehicles (EVs) has been created many challenges and also advantages for grids. One of the most important subjects is capability of which as energy storage device. In this paper, role of EVs has been studied as useful element in microgrids as energy storage device to reduce the on-peak load in microgrid and decrease the total cost of microgrid. For this goal the problem has been considered as an objective function that optimized with Big Bang-Big Crunch optimization algorithm with MATLAB software for the first time and its results have been compared with PSO algorithm. Also, the role of penetration of EVs in microgrid stability has been studied by use of dynamic modeling of microgrid components and the ways to reduce the problems have been proposed. The dynamic simulations are performed by PSCAD simulation software.
***Keywords*-**Big Bang-Big Crunch optimization algorithm, distributed generation (DG), electrical vehicle (EV), microgrid; power market, renewable energy.

I. INTRODUCTION

With the presence of Low-Voltage (LV) utility grids as LV microgrids, and tendency of governments to reduce using of fossil resources, Electric vehicles (EVs) could be mentioned as useful element in microgrids. EVs are important pieces in the microgrid and smart grid puzzle and will play an increasingly important dual role in transport and energy storage. From many advantages of EVs, can state the main role of them to reduce the greenhouse gasses and contaminations, low cost of maintenance, using electrical energy instead of fossil fuels and so on [1]. Because the given communication enabled ability, EVs can reduce the cost of starting of power plants [2]. The expansion of EVs plugging in to the microgrid will continue to add increased load to the grid. However, despite the increased need for energy, according to Pike Research, the added demand of EVs will have minimal impact on grid reliability. This is a result of the microgrid with smart technologies and smart EV charging solutions, which will enable utilities and end users to manage this surge in demand through smart energy management [3].With improving the grids technology toward microgrid and smartgrid, the connection of Vehicle-to-Grid (V2G) has been possible. From the view point of electrical engineers, EVs can act as both load and generator. This issue becomes possible through charging and discharging of EVs' batteries [4, 5]. Recently, some studies are performed on integration of EVs into the electric generation system [6, 7] and also some studies about the effectiveness of EVs on the CO_2 emission and generation unit are performed in [8]. Moreover, the V2G technology can enhance the integration of renewable power resources [9, 10] and reduce the peak power and ancillary service requirement [11, 12].

In this paper, the role of EVs in microgrid as smartgrid has been investigated. For this reason, the impact of EVs on total cost of grid has been studied. To achieve the best solution of cost, a target function has been introduced which the minimum amount of which is optimized by proposed optimization algorithm. This process has been carried out with Big Bang-Big Crunch optimization algorithm and its results are compared with PSO algorithm and also the impact of EVs presence has been studied in grid against the grid without EVs. Moreover, the influence of EVs on grid during disturbances has been studied and the useful solution to relieve the consequences has been proposed.

This paper has been organized as follow: in section II of this paper discusses briefly about microgrids and smart grids, and section III discusses about connections of EVs to microgrids. Section IV introduces control of microgrids issue and discusses about control units. In section V, the total cost of microgrid has been modeled as objective function that must be optimized. The new algorithm for optimization the objective function has been defined in section VI. The simulation results and discussion about them is represented in section VII and finally conclusion is presented in section VIII.

II. MICROGRIDS AS SMART GRIDS

With the presence of Distributed Generations (DGs) as Distributed Energy Resources

(DERs), power grids with huge and complicated structures lead to small grids with low-voltage operation. These types of grids are called microgrids. Because the many useful features of microgrids, the using of which has increased.

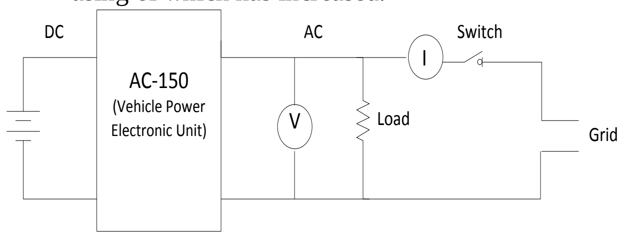

Fig. 1.Connection of battery of EV to grid (Test setup with t-Zero at university of Delaware) [16]

With the promotion of technology, microgrids are going toward smart grids. In this type of grids, every customer is able to buy and even sell energy. The price of energy is changed by time and season. For instance, the price of energy in 2 a.m. (low-load) is lower than 7 p.m. (high-load). So, it is entirely crystal that buying energy by customer in low-load period of time and sell it in high-load duration is economical. This issue helps to reduce the peak of consuming of energy [13, 14].

Realization of this issue needs some operational substructures. One of the most important of which is smart meters. These meters have ability to count the consuming and generating of every customer and can send and receive data to central control unit (CCU). By this way, the price of electricity is determined by Market Regulator (MR) in every moment, and through the CCU is sent to meters and finally, meters count the exchanged energy for every customer on-line. It is necessary to mention that, selling energy by customers just is possible when the generating of every customer is more than the generating of it. So, the extra amount of energy of every customer is sold to grid. This issue shows the advantages of using renewable energies as DGs (like solar cells, fuel cells, wind turbines and so on) for customers and grid administrators. Among these issues, EVs are considered as temporary energy storages.

All of these issues (like interaction among customers and control units) need high-speed communication lines which transfer the signals fast; otherwise, adaptabilities among different units and reach to a smart grid, will be impossible [1].

III. CONNECTION OF EVS AS ENERGY STORAGES TO MICROGRIDS

The meaning of EVs from the point of view of electrical engineers is energy storage ability. So the battery technology is one of the most important issues in EVs deployment. There have been some exciting battery technology advancements in recent times. One of these technologies is Lithium Nickel battery which has been invented. Although fairly complex and difficult at this stage to mass produce, researchers have successfully demonstrated a storage capability some 3.5 times that of lithium ion battery technology. This means that, cars by using these batteries could potentially travel up to about 700km's in one single charge [15]. The average of today batteries for EVs is about 10-70 KWh. The process of charging and discharging of batteries of EVs need special prolusions. The first issue is that Vehicle Batteries (VBs) operate in DC mode. So, we need special unit as Inverter to change DC to ac (to sell energy to grid) and ac to DC (to buy energy from microgrid). A sample model of connection of VB to grid is represented in Fig. 1 [16].

There are many different ways to connect EVs to the grid. The first is through a hard wired link such as an extension cable. Standard wall sockets do not carry the current required to charge an EV quickly, so 3-phase plugs, or high current charge points must be used. Another way of transferring electricity between EV and grid is through ultra-high frequency induction coils. This has been trialed in at least one simulation and it was found that through the implementation of induction coils in the roads at key traffic build up points, energy could be transferred to the EV. This allowed the necessary battery size of the electric vehicle to become as little as 30% of the size as it was being charged through coils in the roads. This could be express as important advantage for EV design as the battery which is currently the most expensive part of an electric vehicle conversion [15].

IV. CONTOL OF MICROGRIDS

One of the most challenging issues in using of EVs as energy storage is marketing management. By this way we need three types of controller [1]:

Microgrid Management System (MMS)
Group of MicrogridsManmagementSystam (GMMS)
Distributed Management System (DMS)

Duty of MMS is controlling the units in each microgrid, and by itself is controlled by upstream units like GMMS, DMS, MR and MO (MR determine the electricity price all over the time). For instance, MMS is in interaction with MR to determine the electricity price in every moment and send it to all customers. The other role of MMS is receiving all signals from customers and counts amount of extra or deficiency of power in every microgrid.

The role of GMMS is in situations which need to deal energy among microgrids. This unit counts the extra or deficiency of power in every microgrid and determines the amount of power that every microgrid must receive or send to others. GMMS, by itself is controlled by upstream unit, DMS. The role of DMS is creation connection between microgrids and main grid. In cases that microgrids have extra energy, GMMS calls the DMS and this extra energy is sold to main grid by DMS, and when microgrids need energy, DMS buys energy from main grid.

With the utilization of EVs, customers are able to save their extra energy in low-load times and sell it to microgrid in high-load times. Dealing energy is only possible with utilization of expressed control units. It is necessary to mention that number of microgrids which able to send and receive energy are limited, because the high distance among them causes increasing the power loss. So, in some situations, trading of energy must perform by DMS.

V. PROBLEM FORMULATION

The main goal of grid performance from the view point of grid operator is minimizing the cost of it. This issue can be achieved by optimal power generation set. So, the problem is defined as total operation cost of microgrid which includes the bids of DGs and storage devices. This objective function is formulated as below [17]:

$$MIN\ f_1(X) = \sum_{t=1}^{T}\left[\sum_{i=1}^{N_g} u_i(t)P_{Gi}(t)B_{Gi}(t) + \sum_{j=1}^{N_s} u_j(t)P_{sj}(t)B_{sj}(t) + P_{Grid}(t)B_{Grid}(t)\right] \quad (1)$$

where $B_{Gi}(t)$ and $B_{sj}(t)$ are the bids of DGs and storage device at hour t. $P_{Grid}(t)$ is the real power which is bought (sold) from (to) the main grid and $B_{Grid}(t)$ is the bid of main grid at time t. U denotes the ON or OFF states of all units, and N_g and N_s are the total number of generation and storage device units. X is the state variable vector includes active power of units and, $P_{Gi}(t)$ and $P_{sj}(t)$ are the active power of ith generator and jth storage device at time t respectively. T is the total number of hours.

The constraint of objective function is mentioned as below [17]:

$$\sum_{i=1}^{N_g} P_{Gi}(t) + \sum_{j=1}^{N_s} P_{si}(t) + P_{Grid}(t) = \sum_{k=1}^{N_k} P_{Lk}(t) \quad (2)$$

where $P_{Lk}(t)$ is the amount of kit load level and N_k is the total number of load levels. This equation denotes the power balance.

$$P_{Gi,min}(t) < P_{Gi}(t) < P_{Gi,max}$$
$$P_{sj,min}(t) < P_{sj}(t) < P_{sj,max} \quad (3)$$
$$P_{grid,min}(t) < P_{Grid}(t) < P_{grid,max}$$

where $P_{Gi,min}(t)$, $P_{sj,min}(t)$ and $P_{grid,min}(t)$ are the minimum active power of ith DG, jth storage device and main grid at time t. The other parameters are similarly true for maximum active power.

The battery limits of EVs include some limitations of charging and discharging rate are as follows [17]:

$$W_{ess,t} = W_{ess,t-1} + \eta_{charge} P_{charge} \Delta t - \frac{1}{\eta_{discharge}} P_{discharge} \Delta t \quad (4)$$

$$W_{ess,min} < W_{ess,t} < W_{ess,max} \quad (5)$$

$$P_{charge,t} \le P_{charge,max};\ P_{discharge,t} \quad (6)$$

where $W_{ess,t}$ and $W_{ess,t-1}$ are the amount of energy storage in the battery at hour t and t-1, P_{charge} and $P_{discharge}$ are allowable rate of charge and discharge respectively. η_{charge} and $\eta_{discharge}$ are the efficiency of battery during charging and discharging. $W_{ess,min}$ and $W_{ess,max}$ are the lower and upper limitations of energy storage. $P_{charge,max}$ and $P_{discharge,max}$ are the maximum rate of charging and discharging of batteries.

To optimize the objective function with considering all constraints, Big Bang-Big Crunch (BB-BC) optimization algorithm is utilized which has been clarified in the next section.

VI. BIG BANG-BIG CRUNCH OPTIMIZATION ALGORITHM

Heuristics algorithms are some kind of algorithms which using a simple way to generate desired answer for optimization the problems and recently, they have been more powerful and famous. The advantages of these algorithms can be summarized as [18]:

- They do not need the complicated mathematical models and also request less initial mathematical variables.
- They do not need initial configurations of values for decision variables; therefore, they may exit from the local optimization space.
- They do not require solution space type, the number of decision variables and the number of constraints.
- The power of computation of them is desired and they do not need the extra time computation.
- Unlike the classic algorithms, they do not require alteration on the interested problems, so they adapt themselves to solve variety of problems.

A. Introduction to BB-BC Optimization

Big Bang-Big Crunch (BB-BC) optimization algorithm is one of the recent heuristic optimization algorithms which has two phases and relies on one of the theories of universe evolution [19]. In Big Bang phase, energy dissipation generates disorders and randomness as candidates' solution, whereas in Big Crunch phase randomly distributed particles and will go toward an order as convergence operator. In BB-BC optimization algorithm which is inspired from evolution of universe, random points are generated in BB phase and will be shrunk to a single point as "center of mass" through BC phase [19] like the other evolutionary algorithms. The point that is described as center of mass is denoted by $A_i^{c(k)}$ is calculated according to:

$$A_i^{c(k)} = \frac{\sum_{j=1}^{N}\frac{1}{Mer\,j}\cdot A_i^{(kj)}}{\sum_{j=1}^{N}\frac{1}{Mer\,j}}\ ,\ \ i = 1,2,\ldots,ng \quad (7)$$

where $A_i^{(kj)}$ is the ith candidate of jth solution generated in the kth iteration, N is the population size in Big Bang phase and Mer^j is merit function for the jth candidate. After The Big Crunch phase, algorithm utilizes the former information as center of mass to attempt generation of new solutions in next iteration for Big Bang phase. This purpose gets executed according to:

$$A_i^{(k+1,j)} = A_i^{c(k)} + \frac{r_j \alpha_1 (A_{max} - A_{min})}{k+1}, \quad i = 1,2,\dots,ng \qquad (8)$$

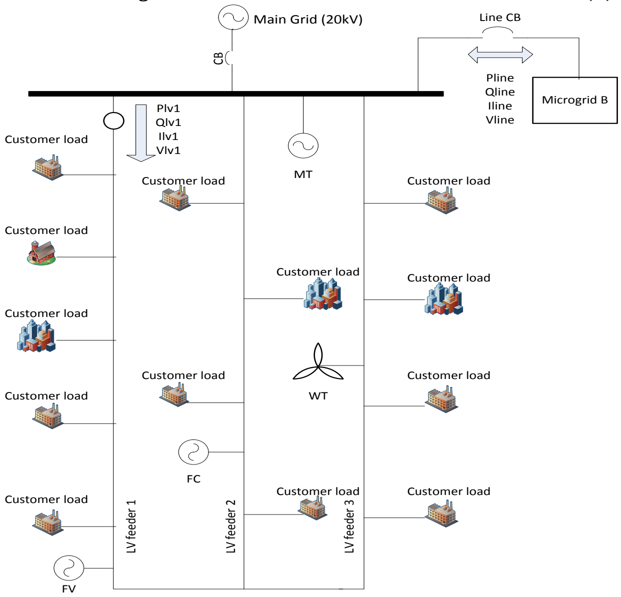

Fig. 2. Studied LV microgrid

TABLE. 1 Bids of the DG Sources

Type	MT	SOF	PV	WT	EV(Batt
Bids	0.45	0.294	2.58	1.07	0.38

where r_j is a random number which changes for each candidate, and α_1 is a parameter to limit the size of search space. These steps will repeat till the stopping criterion has been met and also the number of iterations could be selected as stopping criterion.

BB-BC algorithm does not require the crystal relation between objective function and constraints but objective function can be penalized for some of the design variables till all of the design constraints are applied. Method of utilization of penalty functions is the manner that if constraints be in the permissible limitation, penalty will be zero; otherwise penalty factor has to be applied.

The pseudo-code of BB-BC algorithm can be summarized as follows in five steps [19]:

1) Initial candidates are generated randomly as respects of permissible limitation (Big Bang phase).
2) The merit function values of all the candidates are calculated.
3) The center of mass is computed (7) (Big Crunch phase)
4) The new candidates are calculated around the center of mass in step 3 (8).
5) Return to step 2 until the stopping criterion has been met.

TABLE.2 Comparison Total Cost of Microgrid with and without EVs with BB-BC and PSO algorithms

	Total cost without contribution of EVs ($t)		Total cost with contribution of EVs ($t)	
	BB-BC	PSO	BB-BC	PSO
Best	158.011	162.008	156.527	160.096
Worst	183.390	180.228	180.504	177.758
Average	168.303	171.210	166.304	170.001

TABLE.3 Impact of contribution of EVs on peak load of grid

Consuming with contribution of EVs [MW]		Consuming without contribution of EVs [MW]	
Average off-peak load in 1h	Average on-peak load in 1h	Average off-peak load in 1h	Average on-peak load in 1h
1.051	1.122	1.070	1.174

B. BB-BC Optimization Improvement using PSO Optimization method (HBB-BC)

However, the BB-BC optimization method has the mentioned advantages like the fine search around a local optimum but it has some problems in global investigation of search place [18]. If all candidates of initial BB phase are collected in small area of search space, it is possible that BB-BC cannot find the optimum solution and may be trapped in that subdomain [18]. One solution is increasing the number of candidates to overbear the problem but it causes the increasing the merit evaluation and computational costs. To improve the performance of BB-BC algorithm in optimum manner, it is used the Particle Swarm Optimization (PSO) algorithm which improves the exploration ability of it.

By this way, the Hybrid BB-BC (HBB-BC) not only utilizes the center of mass but also uses the best position of each candidate ($A_i^{lbest\,(k,j)}$) and the best global position ($A_i^{gbest\,(k)}$) to generate a new candidate [20], as:

$$A_i^{(k+1,j)} = \alpha_2 A_i^{c(k)} + (1-\alpha_2)\left(\alpha_3 A_i^{gbest\,(k)} + (1-\alpha_3) A_i^{lbest\,(k,j)}\right) + \frac{r_j \alpha_1 (A_{max} - A_{min})}{k+1}, \quad \begin{cases} i = 1,2,\dots,ng \\ j = 1,2,\dots,N \end{cases} \qquad (9)$$

where $A_i^{lbest\,(k,j)}$ is the best position of the jth particle up to the k and $A_i^{gbest\,(k)}$ is the best position among all candidates up to the kth iteration. α_2 And α_3 are adjustable parameters which control the influence of the global and local best on the new position of candidates, respectively.

To generate the new solutions, it will be utilized the (9) rather than (8).

VII. SIMULATION RESULTS AND DISSCISION

In this part, the results of impact of EVs on grid cost and grid disturbances have been investigated based on the recent mentioned materials. To evaluate the effectiveness of EVs in total cost of microgrids, one sample is illustrated in Fig. 2. The

VBs are considered in residential customers. The bids of DG sources are determined in Table 1.

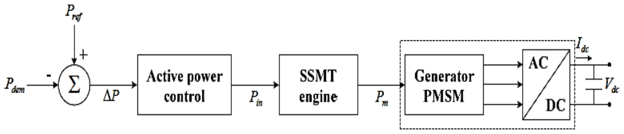

Fig. 3. Block diagram of SSMT.

In the Fig. 2, the Micro-Turbine (MT) has been considered as single shaft MT (SSMT) which its dynamic model is illustrated in Fig. 3 [21]. This dynamic model includes SSMT engine, active power control and Permanent Magnet Synchronous Generator (PMSG) with its controller. The model of fuel-cell (FC) is selected as SOFC model. Its block diagram is presented in Fig. 4 [22]. The dynamic model contains just Fuel processor, FC stack and power conditioner. The photo-voltaic (PV) model is considered as simple model including PV panels and maximum power point tracker (MPPT). Its model is represented in Fig. 5 [23]. Finally, the modeling of wind turbine (WT) has been carried out based on the wind turbine and induction machine modeling.

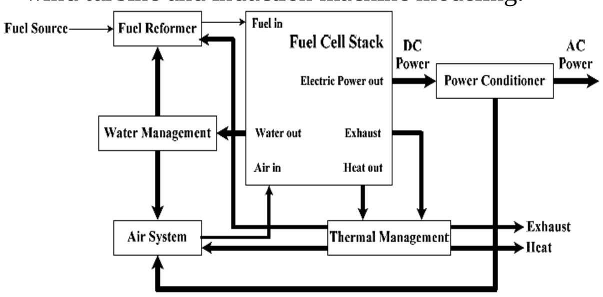

Fig. 4. Block diagram of FC.

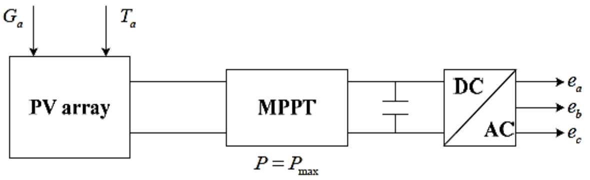

Fig. 5. Block diagram of PV.

The flowchart of BB-BC optimization algorithm to minimize the total cost of microgrid is depicted in Fig. 6. The total cost of microgrid which is optimized by BB-BC optimization algorithm are described in Table 2 and compared with PSO optimization algorithm and also without considering the EVs as energy storage device. As it is clear, the cost result in presence of EVs is more suitable and also the results which are performed by BB-BC are more desired than PSO approach. These results show the effectiveness of EVs from the view point of cost issue. One of the advantages of utilizing EVs in microgrid is reducing of peak load of grid. Actually, the EVs are charged in off-peak load and discharged in on-peak load of grid. This issue is analyzed and clarified in Table 3.

To study the impact of EVs in stability of microgrid, it is assumed that at $t_0 = 0.7$, a two phase fault occurs in microgrid and all the EVs initially have been charged in maximum power value. The dynamic simulation is performed for 1.5 seconds until the microgrid bring back to steady state. During the simulation time, the voltage of the LV bus (rms voltage) of microgrid is measured. This simulation is performed three times with three different amount of P_{EV} (P_{EV}=0.2 p.u, P_{EV}=1 p.u and P_{EV}=4 p.u). The result of this simulation is illustrated in Fig. 7 and the current of LV bus of microgrid during simulation time is depicted in Fig. 8. As it is clear, the deviation of voltage from the steady state voltage value enhances with increasing the penetration of EVs. In high amount of penetration of EVs, the voltage deviation value cannot be mentioned in desired voltage limitation. So, for these situations, the parameter of inverter control of EVs must be modified to improve the voltage deviation. The proposed inverter control strategy in [24] is utilized in this paper. The impact of changing the parameter of K1 of this inverter control is illustrated in Fig. 9 for P_{EV}=4 p.u (K1=1, 100, 1000). As it is clear, increasing the parameter of K1, modify the deviation of voltage. The suitable value of K1 which causes the voltage remains in permissible limitation can be achieved by this way.

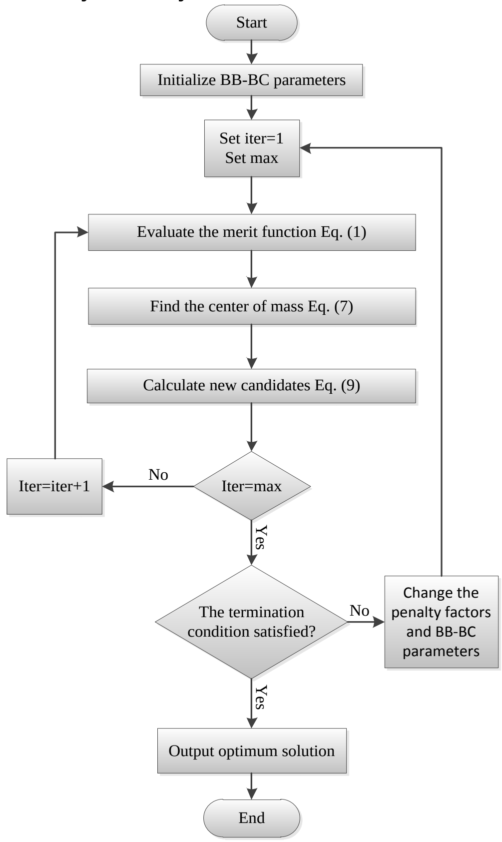

Fig. 6. Flow chart of BB-BC optimization of total cost of microgrid

So, based on the recent discussions, the utilizing of EVs obtains many advantages for customers and utility. But it can conduce to some problems against the grid disturbances. Based on achieved results, the proposed approach to relieve the possible problems is effective besides the cost reduction ability of EVs.

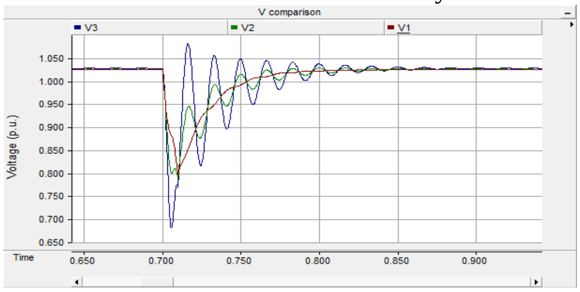

Fig. 7. The impact of EV penetration level on the voltage at LV bus of microgrid (P_{EV1}=0.2 p.u, P_{EV2}=1 p.u and P_{EV3}=4 p.u)

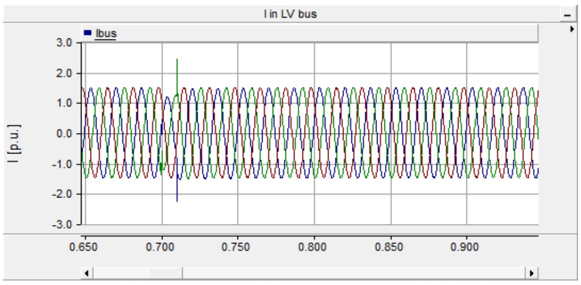

Fig. 8. The current of LV bus of microgrid during simulation time

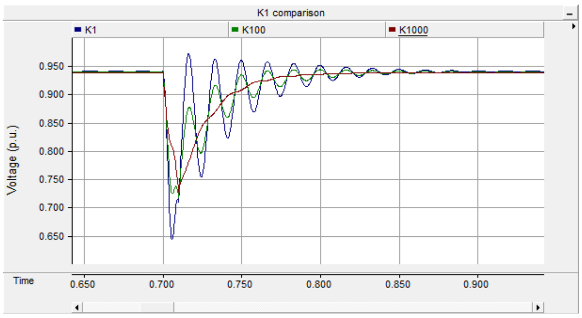

Fig. 9. The impact of K1 of EV inverter on voltage dynamics at LV bus of microgrid (P_{EV3}=4 p.u and K1=1, 100, 1000)

VIII. CONCLUSION

In this paper advantage of EVs in microgrid as energy storage is presented. With the proposed algorithm the reliability of power system is improved and the extra load in the peak of consuming is divided among the low-load durations. By this way, average amount of generating is reduced by managing the energy trade and this benefit belongs to grid, microgrids and customers. The benefit of utilizing of EVs in total cost of microgrid is studied based on Big Bang-Big Crunch (BB-BC) optimization algorithm for the first time and its results are compared with PSO algorithm. The BB-BC algorithm results are more desire against PSO algorithm. Also the impact of increasing EVs on stability of microgrid studied. The result shows that with increasing the penetration of EVs in microgrid, the deviation of voltage enhances. To reduce the voltage deviation, the parameter of inverter control must be modified. The results of this modification were illustrated in this paper. By this way, the desired parameter value of inverter control can be determined.

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